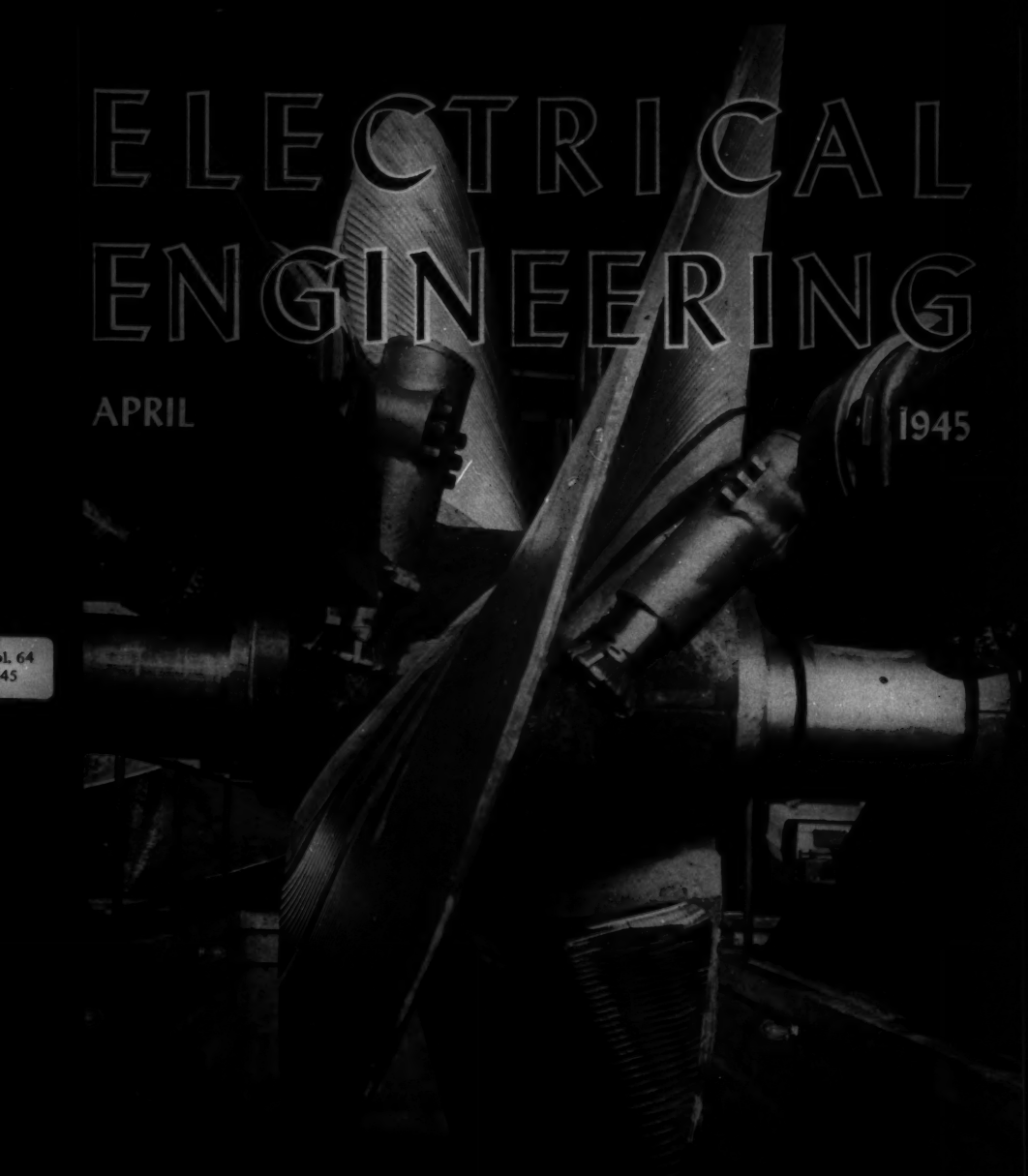
ELECTRICAL ENGINEERING

APRIL 1945



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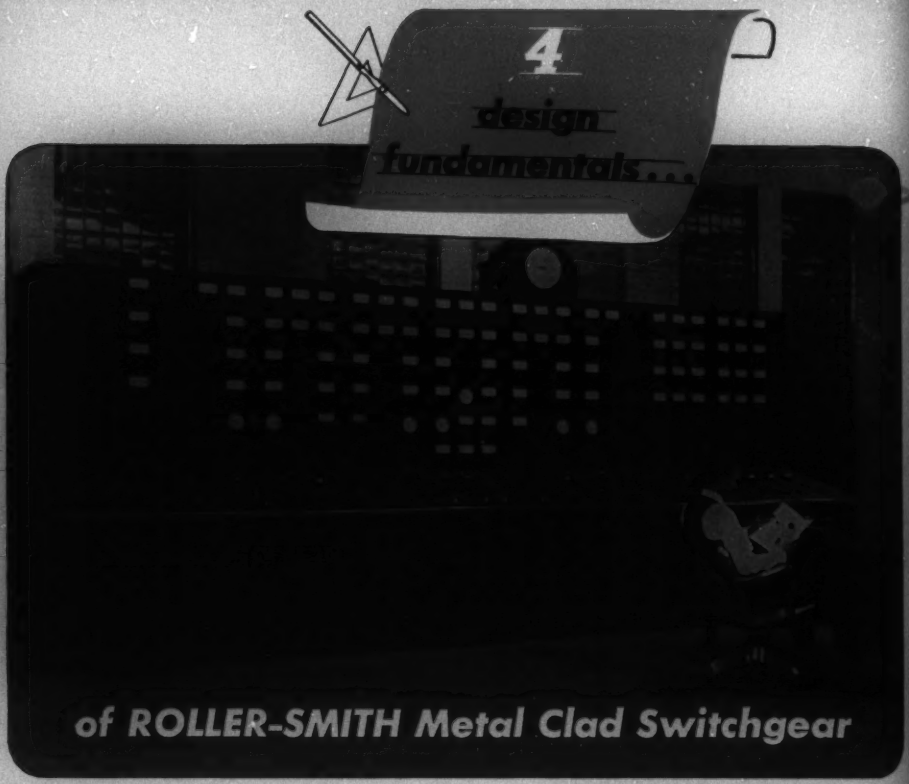

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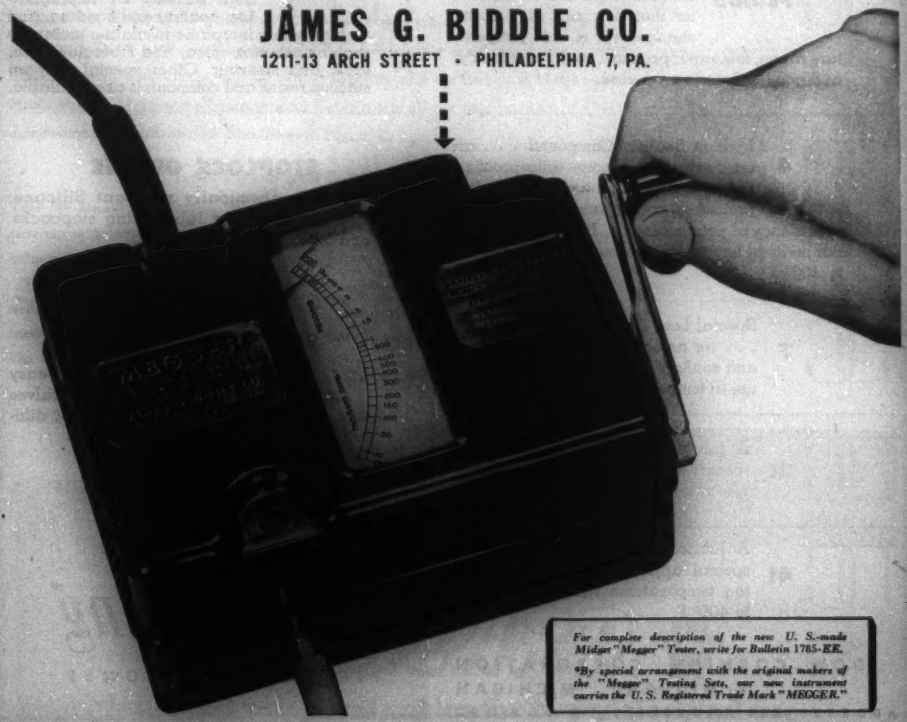

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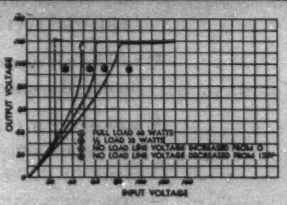

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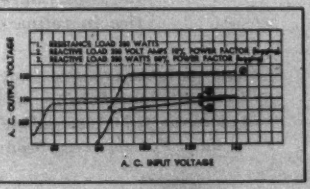
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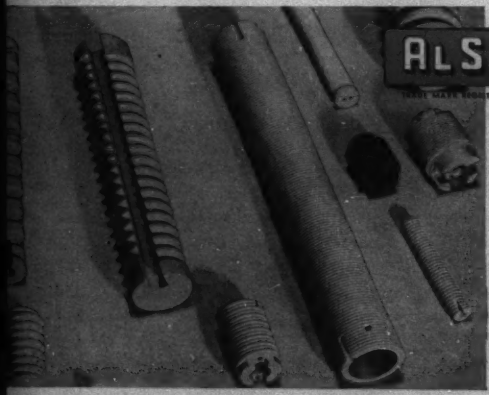

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ELECTRICAL ENGINEERING
VOLUME 64, NUMBER 4 APRIL 1945

The Influence of Research on Victory in War

J. CARLTON WARD, JR.

There is no substitute for continued peacetime research and development and evaluation, if our Nation is to avoid disastrous wars in the future, contends this author, and he quotes various military and naval authorities who support his conclusions.

RESEARCH has had a profound effect on the course of this war. In engineering fashion, to develop the subject, we must start with the causes of war. They are essentially economic, political, religious, or cultural. Because human nature changes but slowly, these causes probably will be with us for as far ahead as we can see.

Now, if we look at our own history some very startling facts appear. For one thing, we have *not* been a peaceful nation. We have fought a major war once in approximately every 20 years, beginning with the Revolution, the War of 1812, the Mexican War of 1842, the Civil War of 1861, the Spanish-American War of the '90's, World War I of the late teens, and now World War II. I have omitted the Indian Wars, the insurrections, and minor troubles such as we have experienced in Central America, Haiti, and so forth.

It seems to me that we, as engineers with that experience, background, and data before us, have to look realistically ahead and project our past experience into the future. I do not predict another war in 20 years, but the experience curve goes off into dangerous and uncertain territory. Unless we introduce some new variables that will control the behavior—the social behavior—of nations, it is fairly reasonable to predict another war.

It is unfortunate that we do not teach the causes of war and the prevention of war instead of a glorified, sublimated, romantic view of wars of the past—for the most part utterly unreal. If you wish to prove that statement, you have merely to read of our American Revolution in a current Canadian school history. You will not recognize your favorite war.

TRAINING FOR WAR

Now, this is too broad a subject for us to try to cover here today, and it is not my title. However, in the prevention of war, or the possible prevention of war, it is obvious that there are some very fundamental considerations—one is having at hand at all times trained men or man power, modern equipment, and a professional group, thoroughly indoctrinated and trained in the art of war, the science of war, or however you prefer to describe the phenomenon of war. This involves our maintenance in this country of professional staff colleges, such as the Naval War College at Newport, R. I., the Army War College in Washington, and also all of the specialized Army schools and Naval schools.

We are very inclined in this country to turn our thinking on and off, politically, like a faucet—the way one throws a switch in an electric circuit. When we are at war, we are very interested in these subjects; when at peace we throw the switch. However, there must be continuity; there must be continued study and application of thought to these problems.

We are interested primarily in one small phase—a very important phase of these problems. That is research as it applies to the scientific side of war and as it ultimately flowers into methods, tactics, and weapons. Matériel is the broad term—and the use of matériel. I do not think I have to defend before you the theory that to be in the air with second-best airplanes is not a healthy place to be; or to be on a battle front with second-best tanks is not exactly an enviable spot; or to be at sea with slow improperly armed and defended Naval ships is not the ideal way to take a sea voyage.

Those are obvious things. Now, those ships, those tanks, and those airplanes were once modern. What made them second best? Obsolescence. Obsolescence in war weapons is a frighteningly rapid phenomenon. The Army today is engaged in defending before Congress a postwar view that aircraft is obsolete in four years. I wish we had the opportunity to discuss in detail that subject. It is fascinating.

I think you will have to agree that the Army's view is not far from a practical measure of what history in the past has proved to be the case. At the moment the political opinions of the country and in Congress support this type of thinking, and so, if we are to benefit in our political structure with a view toward prevention of wars in the future, we should take advantage of this opportunity to set our house in order and elevate our sights for the future.

RESEARCH AND DEVELOPMENT

It is very confusing to the average person to distinguish between the separate spheres of research and development. The terms are loosely used and, to my knowledge, have never been defined in a way with which everyone can agree. For the purpose of our paper today, we divide research and development into three processes.

1. The field of research as exemplified by the work of the National Advisory Committee of Aeronautics in our industry.

2. The field of development exemplified by placing those principles to work by private industry—engineering in a true sense; application of science in a true sense.

3. The field of technical specifications and evaluation, which is predominantly a Government function.

It is well to keep these three factors in mind, and their interrelation, in order to understand the problem as a whole and the politics of the problem. By politics I mean the preservation of a normal peacetime economy in the United States—an economy which will answer to the threat of war with the remarkable performance that you have witnessed in this World War.

GOVERNMENT AGENCIES

During the war we have created many emergency agencies. For instance, we have the Office of Scientific Research and Development and the National Defense Research Council. These are devices to put into Governmental machinery the scientific and research brains of the United States that are normally engaged in civilian activities and pursuits. They

Essential substance of an address presented at the general session of the AIEE winter technical meeting, New York, N. Y., January 24, 1945.

J. Carlton Ward, Jr., is president and director of Fairchild Engine and Airplane Corporation, New York, N. Y.

come from universities, from laboratories, from private life, and from industry. These war emergency organizations are not proper agencies for a postwar period.

At present there is before Congress a bill to set up a national research committee which is being sponsored by the Army and the Navy. It would be a permanent agency to take the place of these wartime temporary agencies. You all know we have the National Academy of Sciences set up by a farsighted administration many years ago with the idea of having available in this country the best brains when and if the country needed them in a national emergency.

The NACA, on the other hand, is a permanent active research institute. The Naval Research Laboratory is another permanent institution covering a separate field, and there are many others. Such is the Government machinery by which the research function in peacetime is accomplished. The development function is accomplished, as I have stated, by private industry supplemented by special projects which at times are operated by the military branches where there is no existing private industry equipped to do the job.

In the evaluation phase there are a great many Government laboratories. In the Army there are the laboratories of the various technical branches of the Army Service Forces, such as ordnance, medicine, signal corps, engineers, and so on. In the Navy, there are the technical laboratories of the bureaus, such as ships, yards and docks, ordnance, medicine, and so forth. In the Army Air Forces there are the laboratories at Wright Field. The Bureau of Aeronautics of the Navy has similar facilities.

When one first reviews such a variety of laboratories and hears them described by various individuals as either research or development laboratories, the pattern is very involved. But if you analyze it according to the three functions I have mentioned, the pattern begins to clarify and the confusion is eliminated.

There is, of course, some overlapping, just as there is overlapping in the application of the words, "research" and "development," but this overlapping is minor. In the postwar world, however, it is very important that these functions be kept clearly separated if we are to preserve the economic structure of this country and maintain a healthy resourceful industry. Each has a permanent place and has a fulltime job to accomplish.

THE CASE FOR CONTINUOUS RESEARCH

A distinguished Naval officer, Admiral Van Keuren, who commands the Naval Research Laboratories, said:

"I think no one will argue against the statement that as long as we have a Navy, so long must we have Naval research, and in my opinion we shall have to have a Navy—and a strong one—for a long, long time. Having been a technical adviser on two reduction-of-armament conferences, and having observed the tragic results and lack of results thereof, it is inconceivable to me that any victorious power will ever let down its guard again to the extent of crippling its Navy, all arguments about armaments bringing on war to the contrary, notwithstanding."

And again from a letter that Admiral Van Keuren wrote in December:

"A fair average in peacetime is about five years from the idea to the application in service, though the range might vary from two to 15 years. In wartime the effort is to compress into two years or less what would ordinarily take five years or more. The result, of course, is that plenty of trouble arises in service, but something is often better than nothing at all. NDRC scientists with whom I have talked agree with the above ideas."

He attempts to set forth there the time between inception and use, which carries you through the research, the development, and the evaluation phases.

Now, from Professor Hunsacker's testimony before the Woodrum committee of the Congress:

"The effects of accelerated enemy research and development in preparation for war helped to create an opportunity for aggression which was promptly exploited. This lesson is the most expensive we have ever had to learn. We must make certain that we do not forget it."

I wish all citizens had time to read the testimony that has recently been introduced before the Woodrum committee of Congress on this subject.

A very interesting development in our Government has occurred which has escaped the attention of most citizens. To look back, our Congress has built up a committee system, over a period of years, by evolution. Many people think it is archaic today, but whatever your view may be in that respect, one thing is clear—that this great country had no single committee of Congress to consider the formulation of an over-all military, naval, and air policy.

Such a task was split up among the Naval Affairs Committee, the Military Affairs Committee, the Budget and Appropriations Committees, the Maritime Committee, as well as various other committees. You can readily see with that organization there could be no over-all simple pattern of national-defense policy emerging. Not until 1944 did this great Nation have in its legislative halls a single committee to consider what is best for the country in formulating a top over-all policy under which these various segments of the problem could dovetail and fit together in a smooth pattern. This committee in the House of Representatives is popularly called the Woodrum committee.

Testimony before the Woodrum committee has been given on such subjects as the question of whether we should have a single department of national defense in place of our War and Navy Departments; the question of what our postwar policies should be on research and development. Many other related questions that should be dear to our hearts as citizens are now being testified to by outstanding experts. From these hearings I am sure will come forth, at least, a pattern of policy which in time should become more and more practical in the light of our past history and our future potentialities as a great world power.

And now, to return to the research and development problem, I would like to give you the example of the Flying Fortress. This airplane was started away back in 1935. It was not a good war-developed fighting machine until 1942—seven years. Probably you think of the Flying Fortress, as you properly should, as our first large air bombardment machine. Can you imagine what the results would have been, had we had to germinate and develop that idea since Pearl Harbor? The successor machine, the Superfortress, was started in 1939, and only just recently has the Army announced it as a battle-perfected bomber.

In this one example you can see the major argument for continued research and development. We do not like to say it, but we were a second-rate Naval and Army air power when this war hit us. You do not find many of our aviation leaders saying that. You do not find many of our military leaders saying that, but those are facts. Testimony has put them before Congressional committee hearings.

When I was in France in 1940 on an official mission and the Germans were breaking through in the North, a French air general said to us, "If America can give us about 500 modern pursuit planes and 600 tanks, we can stop the breakthrough." Our reply had to be that our country did not have 500 modern pursuit aircraft, nor did we have any modern tanks in 1940. Had *we* been attacked as France was attacked, you can draw your own conclusions.

You know that there *was* such a plan to attack us. That plan remained active in the German general staff until after the battle of Stalingrad in 1942. Many American citizens have not been alive to this fact.

THE FLYING FORTRESS—STAR WITNESS

So, to go back to the Flying Fortress, as our example, you find seven years of development and research and evaluation before you had the finished article. The first Flying Fortresses that we sent to England were defective in the sense that they had what we called blind spots in the tail. A great many of them perhaps were needlessly lost in the first missions on which they were sent.

I would like to read from General

Frank Carroll, who commands the engineering division at Wright Field, who spoke before the Society of Automotive Engineers recently. To quote:

"Let us look for a moment at some of these hurdles that research had to take before the *B*-29 could take to the air. High altitude means reduced temperature and reduced pressure. The effects of these two circumstances had to be counteracted because they not only influenced the operation of nearly every component of the aircraft, but they had a very definite effect upon the men who flew in them. As atmospheric pressure goes down, the horsepower of an engine is cut proportionally, so that its sea-level output is reduced 50 per cent when an altitude of 20,000 feet is reached. To keep up the manifold pressure, turbosuperchargers were designed, and problem number one was disposed of.

"But that was only the beginning, ignition systems were affected by high altitude also. If we maintain the same high pressure within the cylinders at high altitude that we normally maintain at sea level, then the ratio between the internal pressure and external pressure is increased. Electricity following the path of least resistance will tend to 'arc over' somewhere in the low-pressure area outside the cylinders rather than leap the spark-plug gap and ignite the compressed gasoline vapor within the cylinders. The electrical engineers have gone to work and developed new insulating materials with higher dielectric characteristics and have redesigned the ignition harness to increase creepage distances, and we have taken hurdle number two.

"We now have high enough manifold pressure, and the ignition system is operating, but our engine is still not operating efficiently, because the reduction in pressure has caused the gasoline in the tanks and fuel lines to vaporize, causing a loss of fuel and the formation of vapor locks within the lines. The design of tank and booster pumps takes care of these problems, and we have the engine running, but there are still more problems to come.

"The thin air at high levels is now found to give insufficient cooling, and the whole problem of heat transfer is opened. The research boys go to work again and redesign the cowl flaps, oil coolers, and the ducting around the cylinders. Others develop new materials which will withstand higher operating temperatures, and we at last have some of the engine problems pretty well in hand. Thus it will be seen that simultaneous research in all fields is necessary to keep our scientific progress from faltering. One missing link in the chain of development may well hold up an entire program.

"So far we have only considered powerplant problems, but the human mechanism must be provided for as well. Man, like an engine, loses efficiency as the atmospheric pressure about him is reduced. To keep up the human manifold pressure, to use a simile, pressurized cabins were designed for the *B*-29. A pressure cabin may be used in one of two ways. It may be used to eliminate the need of wearing oxygen masks on long missions by maintaining a simulated altitude below 12,000 feet, or it may be used to prevent bends by maintaining a simulated altitude below 30,000 feet. The *B*-29 may be operated with a pressure differential up to 6.5 pounds per square inch. This will permit operation up to 30,000 feet while maintaining an 8,000-foot cabin altitude.

"There were originally many fears about the use of pressurized cabins. It was thought that, if shellfire penetrated the pressurized area, the sudden drop in pressure would cause serious injury to the air crew. Some even contended that a man's eyes might pop right out of his head. However, before new equipment of any sort is installed in an Army airplane, it is subjected to tests as rigid as those of the airplane itself.

"The aeromedical laboratory of the engineering division at Wright Field was called upon to make conclusive tests on explosive decompression, as this phenomenon of suddenly reduced atmospheric pressure is called. A mock-up cabin was equipped with an oxygen system, a communication system, and a time-pressure recorder designed to make an accurate time tracing of rapid pressure changes. To make sure that the record would be complete, high-speed motion-picture cameras were also installed.

"The cabin was placed in a high-altitude chamber, such as is normally used to test the effects of high-altitude flight on personnel. A volunteer entered the cabin, and this very exciting simulated flight was begun. Pressure was maintained within the cabin equal to that existing at approximately 10,000 feet, whereas the pressure outside the cabin was reduced to that existing at an altitude of 35,000 feet. By means of doors with heavy paper apertures of different sizes, it was possible to puncture the cabin suddenly and thus reproduce the condition of explosive decompression in combat flight. This first test was highly successful, and the same test was afterwards performed more than 150 times (on different people), and there were never any bad effects.

"The pressure differential here was the same as that used in a bomber, 6.55 pounds per square inch. The decompression rate (87 pounds per second) was the same as would be produced if a pressure cabin of 1,000-cubic-foot volume was ruptured with a $5^1/_2$-foot-diameter hole. No ill effects were observed on any of the subjects. There were no latent symptoms. At the moment of decompression the subjects experienced a sense of inflation of the chest and abdomen. They were able to put on their oxygen masks and to unscrew the bolts on the cabin door, a fair indication that a pilot would be able to fly his plane to a safer level if his pressure cabin should suddenly leak.

"Pressurized cabins are now taken as a matter of course by the boys in the *B*-29's. Pressurization is considered a normal part of the airplane. One *B*-29 crew, flying across The Hump from India to China, hauling critical supplies, had a failure in one of the scanning blisters. A quick-witted gunner thrust a seat cushion into the hole and the flight was completed successfully without further event, and without loss of cabin pressure. In fact, they were so busy that they made several flights before replacing the blister.

"Placing the men in a pressurized cabin did not solve all the problems. The turrets and guns had to be operated. It was impractical to pressurize the entire fuselage, and so we had a choice of building pressurized cabins for each gunner *or* to build a large central cabin and design a remote fire-control system.

The General Electric Company started a development of three elements that now compose the system, years before the war. They then had to correlate those three developments into a remote fire control system.

"We chose the latter, because it gave the gunner better visibility, more comfort, and more protection from enemy fire. The system was designed to do more than remotely operate the guns, however. The system includes the automatic correction for altitude, temperature, ballistic characteristics of the ammunition, and the speed of the *B*-29 as well as that of the attacking planes. These factors are all automatically determined by the computer during tracking, and instantaneous and proper adjustment is made in the aim of the guns. Until recently there was a legitimate question as to whether one could actually shoot down attacking fighters with such remotely controlled armament. Well, that was until recently. Headquarters communiques from the combat areas seem to show that it is not only possible, but that the fire-control system is working out even better than we had hoped."

AVIATION'S ENGINE DEVELOPMENT

Now, let us turn to aviation's engine development for a moment. What I have to say is not at all intended to be critical of another great American industry. It merely is intended to indicate that one who is not skilled in a specialized field can easily underrate the problems of that field when entering it. If you turn back to certain publications, newspapers, trade magazines, and other vehicles for the dissemination of popular information in this country, you will recall that about 1940 the automotive industry was making great claims of what it was going to do in the production of new aviation engines to revolutionize this industry.

That was going to be brought about by adherence to automotive principles and experience, and, of course, it was with the idea of winning the war. One organization published some pictures of its engines which were of a new type, and it was stated that there were many new principles involved in them. To my best knowledge, these engines have yet to fly.

In 1944 another great automotive company started the design of what to them was a revolutionary large engine. That engine is yet to make its first flight and is now two-thirds the horsepower of the equivalent large engines of the old-line aircraft-engine manufacturers. I bring that out, not to criticize a great industry that has done so much in the production field to win this war, but to caution people who underrate the experience required in research and from skilled personnel who must maintain continuity of technical experience in any particular field.

One may be the greatest electrical engineer in the world, but he might have

quite a bit of difficulty in building highways in the civil-engineering field. I do not think that the problems of development of highly diversified equipment are as far apart as this example, but the old saying is that every man should "stick to his last." Perhaps that is too general to be a fair statement. There have been contributions made by the automotive industry to the technique of aircraft and engine production, particularly, through the adaptation of some of their specialized processes to the aircraft field.

We owe a tremendous debt to the automotive industry, but had we depended upon that industry's aircraft production—no matter how extensive their laboratories, their technicians, or their resources—it is doubtful that we would be anywhere near where we are today. However, if the aircraft industry had attempted to build automobiles, the shoe would be on the other foot, and the end result the same.

As to aviation-engine development, I was privileged to make a study in Britain in 1942 of British experience and found that responsible officials of the Ministry of Aircraft Production would not make a statement that any major aircraft engine in Britain had been developed in less than six years. In this country, we have records of approximately five years that I know of personally. I have heard claims of less than that, but I do not know of any such instances.

Thus, the problem of aircraft engines, for instance the Allison, is very interesting. That engine started in approximately 1930, and it had ten years of development experience before the war began. In our own case our Ranger engine had been started in 1928 and had gone through successive developments before it became a production engine for the war in 1941 and 1942.

In airplanes the Douglas *B*-19 is a typical case of courageous development work. This is the huge Douglas bomber you probably saw illustrated before the war, the tail surface of which looked as high as a five-story building. It probably is the largest flying laboratory ever built in the history of the world. Only one was ever constructed. It cost many millions of dollars. This *B*-19 is a flying laboratory in which priceless experience has been gained, out of which the heavy bombers of today have grown.

IMPROVEMENTS IN ARMAMENTS

Turning to the field of armaments, we have the interesting question of guns. Our best medium-caliber guns, particularly in the antiaircraft field, stem from European developments. The reason for this is the United States has never had an equivalent ordnance industry or comparable ordnance development during peacetime. We have had to draw on foreign industry since we have not had continued research of our own. I am not undervaluing the work of our ordnance departments. They did not have the funds. There was no private industry and no market for such a product. Thus it was the foreign ordnance firms that sold their wares in international trade on whom we had to draw for much of our ordnance experience for this war. We have developed some unusually fine ordnance, but we must not forget, in our patriotic American way, that there are other people in the world at work and that frequently we absorb their ideas without intending to appropriate them.

The question of jet engines is one that right now has a great deal of public interest. Like the helicopter of a few years ago it has been made to appear out of focus. The helicopter of a few years ago was going to take off in your backyard and land at your golf club. It was going to be the postwar personal airplane. I do not think it had any limits in the minds of people who drew pictures for popular magazines. Today it has settled down into what it should be—a useful piece of aircraft equipment with new performance characteristics not found in other types, supplementing the other types, enlarging the field, but not displacing the field.

At this date, it is fair to say that jet engines should be so considered. Fuel economy is still a very definite problem in jet engines. There is a new German airplane, I believe, the Messerschmitt 163, a single-engine interceptor rocket jet job. It goes at a speed of about 500 miles an hour and has a perfectly amazing rate of climb beyond anything that we have at the moment, and some very potentially unpleasant implications for us.

That particular airplane, however, is confined to what we call airport operation. It must work very close to its home airport. It drops its undercarriage the minute it takes off, and then shoots up like a rocket, and will go through a bomber formation at a speed so great that even fire control is not too effective against it. It does not maneuver. It just goes on its way.

When it penetrates above the bomber formation, it pauses, turns off the propulsion machinery, and cruises around as long as it can by gliding, waiting for a victim to appear. Soon it has exhausted its fuel and lands wherever it can. It cannot always go back home and frequently must be trucked back to its airport or home base.

Then there is another two-engine Messerschmitt, I believe it is the *Me* 262, which is a jet job that the Germans have produced. It has range, and it has more of the characteristics of an ordinary airplane. It is assumed to have 550-mile-an-hour performance. It too has limitations, but there is no use denying the fact that the Germans have been first in the jet field.

Yes, we have jet airplanes, but let us not fool ourselves. We are late with them. The Bell airplane—the first American one to fly—today is designated a trainer. The second one which will fly is the *P*-80—now in production. But the Germans have jet planes in their squadrons. They have been seeing service for some time.

There are other cases where we have been behind the enemy. We do not like to admit it, but he has been at work with continued research in the art of war while we have been going about our peaceful way with refrigerators and radios.

Let us take radar. Radar presumably was conceived at the Anacostia Station of the Naval Research Laboratory by two scientists in Naval employ. At least the principles were developed there. But, if I am not mistaken, the British were the first to utilize radar in a major way during the battle of Britain. By means of radar, 700 of their fighters stood off 2,400 German attacking craft and annihilated such a high percentage of them that the battle of Britain was won as a defensive battle by Britain.

The technique was simple. Radar located the enemy before he had approached the shores of Britain. Radar determined roughly the type of airplane and their quantity so that the high command in Britain was able to have its airplanes off the ground and in the air at a predetermined spot where the German airplanes were likely to arrive. The Germans instead of annihilating the British aircraft on the ground, as they had done the Polish, found Spitfires and Hurricanes in the air ready to do battle. This they did so effectively that they won that phase of the air war.

ENEMY EXPERIENCE CORROBORATES ALLIES

In defensive warfare the German airplanes were defective. They were defective because of a German policy—not because of a lack of ability in the technical field. That policy was to design their airplanes for offensive purposes essentially as air co-operative ground support. So, the British took advantage of this weakness with the superior offensive performance of their Spitfires and Hurricanes and took a frightful toll of the Germans. It took Germany several years to reorient her policy and produce airplanes in the attack field that anywhere near approached those of the British.

You find all through these examples one single theme. *There is no substitute for continued research and development and evaluation.*

Examples in many other fields could be mentioned. Frankly, we were not up with our enemies in torpedoes. There may be some Naval people who would deny that statement, but it is not my own. It comes from persons who are considered competent in these fields. And again it had been lack of funds for continued peacetime research and development.

You all know there is much argument concerning whether our tanks are better

than German tanks. Our tanks are mobile, fast. The German tanks are ponderous, heavily armored, and heavily gunned. For some types of operation, the German tank is definitely superior. For some types of operation our tanks are superior. We followed divergent courses, just as was the case with German and British aircraft. Peacetime development and military study and evaluation could have solved this problem and provided us with a wider choice of tanks.

Let us turn to another country for an example to demonstrate our thesis. In Italy, an impoverished nation founded the city of Gidonia, which was devoted entirely to aviation research. They had more wind tunnels located there than we had in the United States. At the same time the German *DVL* Laboratories and similar institutions so far surpassed our NACA and the sum total of other American laboratories that it is fair to say we were probably not much more than a third or a fourth as great in the field of research, quantitatively speaking.

Fortunately for the United States, for some years our NACA had led the world, and we lived on that momentum. But time was running out, and, as I have said earlier we were a second-rate air power because of lack of funds for continued development and research, relative to what our aggressive enemies were spending.

I do not know much about Japan, but we undervaluated Japan seriously. We called them "copycats." If you examine the instruments, the engines, and structures of Jap aircraft that have been shot down or captured and brought to our laboratories for dissection and study, you will dispose of that idea. They did what any nation would have done in the initial stages. They borrowed from every country in the world—French licenses, British licenses, German and American licenses. For example, out of all of that pooled information they frequently built an engine that had American-type parts and German-type parts and French-type parts, all in the same unit. They borrowed from any source available, but they did not stop there. They built laboratories and went to work and produced, in some fields, devices that are superior to anything we happen to have in the corresponding field.

We must not underrate or undervalue the Japs. They are doing original work and under the desperate conditions in which they find themselves today as a nation, I think you will find continued and rapid progress on their part.

You all remember the attack on the cruiser *Savannah* by a guided missile. You may recall that it took us quite by surprise. The Germans were using forms of guided missiles, controlled by radio or by other means.

Similarly, the robot-bomb development in Germany is now ten years old. Had it been ready for service and in use one year earlier, some authorities believe that the course of this war might have been drastically changed. That is a pretty close margin, isn't it?

At this late date we have copied the German robot bomb, and I presume that you soon will hear about ours being superior to theirs. We often have to do what the Japs did—copy something, and set out to improve it. I have no doubt we will improve it. But let us remember we borrowed it from the Germans. I might say we borrowed it as an engineer traces a blueprint. Of course, there are newer types of robot bombs under development.

AIR WAR BLAZES RESEARCH TRAILS

General Arnold in a closed meeting for the aircraft industry last fall said that two great developments had come out of the air war—the ability to fight in the air without pilots or human crew, and the mass use of air-borne troops. Each development requires completely new engineering material for which there is no past background or pattern.

To illustrate the problem, our company, at the request of the Quartermaster Corps, undertook to redesign a refrigerated truck. From memory it weighed approximately 15,500 pounds, exclusive of the motive-power unit. When we got through it weighed a little over 7,000 pounds, carried the same load, performed the same duty, but not with the same construction. We used airplane methods of design, whereas the truck had been built in accordance with automotive methods. If you figure a truck empty weighs over 15,000 pounds, and you have to take it loaded through the muddy roads of Italy and over bridges not made for more than donkey carts, you can see the problems to be solved in moving a mechanized army up to the front.

In utilizing air-borne troops, this problem is more serious. You cannot afford to take the kind of guns and gun mounts in by air as you do over the ground. And so it seems perfectly reasonable to assume that much of our ordnance, much of our matériel, ultimately will have to be redesigned for air-borne operation.

Our Army now has field kitchens that can be flown in by air, designed for light weight and compactness. They also have equivalent field hospitals, X-ray apparatus, field bakeries, field ice-cream plants, as well as mobile trucks and other troop matériel.

Aircraft, as well as ordnance, is going to have to be designed for that type of operation. Airplanes are going to have to be more like cargo ships and less like *Queen Marys*.

ELECTRICAL ENGINEER IN VITAL ROLE

In all of these problems the role of the electrical engineer is vital. Colonel Holliday at Wright Field, in charge of the electrical-engineering section in General Carroll's engineering group, had been discussing this problem with me. I needed considerable help, and he supplied it in admirable fashion. He stated:

"In general the electrical industry has done much for the war effort of the Army Air Forces. Proof of this lies in the fact that no tactical airplane can accomplish its military mission unless its electric system is functioning efficiently and reliably. For example, a bombardment airplane cannot navigate to its objective, operate the bomb-sight, drop its bombs, or fight off enemy fighters, unless the electric system is operating.

"Much of this has been due to the fact that the electrical industry has increased the power available from engine-driven generators to an almost unbelievable extent without asking for any increase in space and little increase in weight. In five years the output has been increased 16-fold with an increase of less than 50 per cent in weight and no increase in the allowable dimensions on the engine-accessories section. Similar but not so outstanding increases in performance have been made in electric motors. However, much remains to be done.

"One exception in which the electrical engineer has not produced an equivalent answer lies in the wheel brake. There has been some demand for an electrically actuated wheel brake which would make it possible to produce an 'all-electric' airplane.

"Electrical engineers should further study their designs to improve reliability. Life of many electric accessories is altogether too short. Further, some electric accessories on failure become more of a hazard than the simple omission of an accessory. It is essential that potential failures in electric apparatus be minimized to insure that the device will be safe in the event of failure.

"Continuous effort must be expended to reduce the weight of electric accessories. As airplanes increase in size and range, the importance of weight becomes still greater.

"Because many members of the electrical industry operate with a small financial investment, they also produce equipment to poor standards of performance. The industry itself should, by means of its own organizations, combine to eliminate such production, because failure of one manufacturer to produce satisfactory equipment will be an indictment on all.

"Electric accessories which will be needed in the future include the wheel brake already mentioned, automatic controls, motor-driven actuators, an electric system of cabin pressurization, better instrument lighting, improved external lighting equipment particularly from the aerodynamic viewpoint, air-conditioning equipment, improved cabin lighting, and other accessories which go with luxurious air travel. The field of automatic controls has hardly been touched. The airplane has become such a complicated machine that no one individual can possibly know enough to watch continuously performance of various parts and prevent operation under a critical condition, thereby risking failure. The electric system can take over this task and do it easily.

"Motor-driven actuators to do the same work as hydraulic actuators are badly needed. Most of the actuators now available are too complicated and heavy. Component parts

do not have sufficient reliability. Anything to improve this situation will be welcomed by the aircraft industry.

"Aircraft lighting for too long has been solved with the simplest designs. The time has come to study lighting seriously, not only at the instrument panel, but also in passenger compartments, to produce levels of illumination and arrangements of lighting which will lead to the utmost comfort."

WEIGHT-SAVING MATERIALS

We also discussed the use of aluminum wires and cables in aircraft to save weight. I had been deeply interested in that subject during my period in the wire and cable industry. There are large savings in weight to be realized in aircraft by the use of aluminum for conductors where properly applied. For instance, you would defeat your objective if you had to put them in steel conduits because of their larger diameter. Just why they have been so long in coming I do not understand. It may be due to the inability to work up proper electrical standards and to have them adopted by the services who must operate on the basis of procurement specifications. If the electrical industry does not produce the specifications and have them approved, they cannot be specified for procurement.

ELECTRICAL PROBLEMS

In a discussion I had with General Carroll he emphasized the importance of electrical engineering in aircraft somewhat as follows:

All airplanes are becoming flying power plants. The fire control is obviously an electrical problem. In a *B*-29, for instance, there are 20 different radio and radar sets. Flight controls are electric. The bombsights and bomb racks are electrically operated. The landing gear should be operated electrically. Electrically heated blankets and corresponding outlets must be provided. The flight personnel are encased in electrically heated suits. The main-engine-driven generators must be of high-altitude types and subject to the limitations of weight and space already mentioned.

Auxiliary power plants are now required in order to furnish power on the ground, because batteries are too heavy. A-c systems of higher voltage are needed in the modern large airplanes. There are millions and millions of feet of power wiring used, and weight is important. High-voltage a-c procedure should greatly eliminate such weight.

Today we still use the low-voltage d-c systems. Instruments are largely electric. A number of electronic applications are too secret to list. Our propellers often operate by electric mechanisms. At time we have ignition problems of a serious character at high altitude. These, he stated, are just a few of the applications and problems.

Interesting is the fact that, in *B*-29 operating squadrons based in the fighting areas, it is now necessary to have a highly experienced electrical engineer stationed with each squadron.

So, you see the electrical engineer should play, and is playing, an extremely important role. We need continued peacetime research and development if our Nation is to avoid disastrous wars in the future.

E. F. W. Alexanderson—1944 Edison Medalist

In recognition of his "outstanding inventions and developments in the radio, transportation, marine, and power fields," Ernst F. W. Alexanderson was awarded the AIEE Edison Medal for 1944. The presentation was made at a joint meeting of AIEE and the Institute of Radio Engineers during the 1945 AIEE winter technical meeting.

THE EDISON MEDAL, highest honor of AIEE, was awarded for 1944 to Ernst F. W. Alexanderson (F '20) consulting engineer with General Electric Company, Schenectady, N. Y., at a joint session of AIEE and the Institute of Radio Engineers, January 24, during the 1945 AIEE winter technical meeting in New York, N. Y. Presentation was made by C. A. Powel, AIEE president, who stated that the honor was conferred upon Doctor Alexanderson in recognition of his "outstanding inventions and developments in the radio, transportation, marine, and power fields."

Karl T. Compton, chairman of the Edison Medal committee, and president of Massachusetts Institute of Technology, Cambridge, Mass., outlined the history of the medal which was established by a group of associates and friends of Thomas Edison to serve as "an honorable incentive to scientists, engineers, and artisans, to maintain by their works the high standard of accomplishment" set by Edison himself, and which has been awarded annually by the AIEE, with two exceptions, since 1909.

The career of the medalist was narrated by R. C. Muir (F '36) vice-president of General Electric Company, Schenectady, N. Y., and long-time associate of Doctor Alexanderson. Inventer of the alternator which made the first radiobroadcast possible, Doctor Alexanderson holds some 300 patents in radiotelephony and telegraphy, television, motors, generators, power transmission, vacuum tubes for radio and power rectifiers, electric ship propulsion, and electric traction.

Full text of Doctor Muir's address and Doctor Alexanderson's response follows.

The 1944 Medalist

R. C. MUIR
FELLOW AIEE

Doctor Alexanderson during all the time I have known him has always had some difficult problem to wrestle with, and fortunately he has been a very good wrestler. It was back in 1905 while testing a new kind of alternator that I first met him, and since that time his name has always been before me in connection with one new development or another.

The single-phase railway motor, the 100,000-cycle radio alternator, multiple-tuned antenna, selective tuning for radio receivers, facsimile broadcasting, thyratron exciter, thyratron control, thyratron motor, high-voltage d-c transmission, electric ship-propulsion control, and Amplidyne control are all mileposts along the path of engineering progress which have been erected by Doctor Alexanderson. He has been granted more than 300 patents on inventions which embrace a large part of the electrical field and which bespeak his ingenuity, versatility, and activity.

I once received a postal from a friend which started thus: "It is a bright crisp morning, and I am as full of pep as an Alexanderson alternator." He might have said that he was as full of pep as Doctor Alexanderson himself, and it would have conveyed the same meaning to me.

It is the human side of Doctor Alexanderson that is not so well known. Many people have the notion that someone who acquires great distinction in the field of art, science,

engineering, or invention, is not otherwise normal and cannot be approached or talked to as we talk to an ordinary person. It is true that there are a few famous temperaments among the famous. But most of the famous people I know, like Doctor Alexanderson, are human beings too.

He loves people. Possibly his favorite sport is sailing, a sport to be enjoyed with others. Aside from giving a great many the enjoyment of a sail in his *Nordic* on Lake George, he has taught others to sail, and his enthusiasm has spread so that sailing races, in which he enthusiastically participates, are held each week on Lake George throughout the summer months. He likes to walk, to swim, to dance, to skate; he even plays bridge with enjoyment and some luck. He enjoys good music and does not mind taking part in a rousing song. As L. A. Hawkins, executive engineer of the General Electric Company research laboratory has said: "Afloat or ashore, Alexanderson is always a genial and stimulating companion, while his straightforward character and his unaffected good fellowship make him a lovable friend."

He loves to work with young people, and they like to work under his guidance. To use his own words, "The relationship between the older and the younger generation should be one which is not characterized as a boss and an assistant, but one of teamwork where the younger generation supplies the knowledge of the latest technical development and the older generation contributes experience and imagination. The relationship is intimate and personal." These are his own words, and my observation is that he carries out these principles wholeheartedly.

It undoubtedly has had much to do with keeping him young and alert. After 40 years of engineering, he is still turning out inventions and stimulating his younger associates to do likewise. An early associate who has been granted 90 patents has told me of the tremendous stimulation he received from Doctor Alexanderson. One of his younger associates has to his credit 74 patented inventions, and another 54.

In recent years one of his most important contributions has been in connection with power amplifiers and positioning-control projects carried out largely by younger men under his direction. Notable among these is his joint invention with his assistant, M. A. Edwards, of the Amplidyne, an armature-reaction-excited and fully compensated type of d-c machine that is actually a two-stage amplifier. This is the basis for the electronic control of turrets and guns in our airplanes, for antiaircraft guns on land and aboard ships, for searchlights, antenna, and other applications where quick and accurate response and amplification of power is necessary. Fortunately, it also has many applications in peacetime industry.

It has been my good fortune for many years to have Doctor Alexanderson discuss his new projects with me, and I have always had difficulty in following him. We agree on the objective and I usually understand the initial steps. I lose him quickly, however, as he hurdles the many problems on the way to the end result which he always seems to see quite clearly. My impression is that he has a powerful intuition which enables him to see through the problem clearly, and he just does not worry about the obstacles along the way. Probably that is one reason the young men like to work with him—they clear up the obstacles.

AIEE President C. A. Powel congratulates E. F. W. Alexanderson after the presentation of the Edison Medal

Doctor Alexanderson has had many honors bestowed upon him. In 1919 he received the Medal of Honor of the Institute of Radio Engineers, and in 1924, the Knighthood of the Polish Order of Polonia Restituta, and, in 1928, the John Ericsson Medal. In 1934 he was elected to the Royal Academy of Sweden, the body which bestows the Nobel Prizes in Sweden. In 1940 his name was listed in the Hall of Fame at the World's Fair for foreign-born citizens who had contributed most to the United States. In August 1944 Doctor Alexanderson was awarded the Cedergren Gold Medal of the Royal Technical University of Stockholm in recognition as a writer of prominence in electrotechnics.

He is a Fellow of the American Institute of Electrical Engineers, a member and past president of the Institute of Radio Engineers, and a charter member of the Institute of the Aeronautical Sciences. He has a long record of service in these technical societies.

He has honorary degrees of doctor of science from Union College, Schenectady, and doctor of philosophy from the University of Uppsala, Sweden.

As a close friend, admirer, and associate, I am delighted that the committee has chosen Doctor Alexanderson for this highest of all honors in the field of electrical engineering—the Edison Medal.

The Edison Tradition—A Challenge to Industry

E. F. W. ALEXANDERSON
FELLOW AIEE

I deeply appreciate the honor you have bestowed upon me in the award of the Edison Medal. However, in accepting it, I feel I do so in full recognition of the honor it symbolizes to the General Electric Company and the many engineers closely associated with me in my many years of work for this company.

I feel that in the acceptance of this medal we are also paying homage to the great inventer and the great American, Thomas A. Edison. In doing so we may give some thought to the place of invention in our social order. Invention must in this connection be given a broader meaning than the usual one. Here it should mean resourcefulness in dealing with new situations and eagerness to put new ideas to practical use. There are many times more inventions and inventers than there appear in the patent records. It is this great backlog of talent that is the strength of our

Nation and which has given the United States the reputation of a nation of inventers. As a symbol of American inventiveness, still stands out alone the name of Edison, the creator of the electrical industry which has more than anything put its stamp on life and society since the beginning of the century. As America was seen from across the ocean, distance lent even greater enchantment, and to the name of Edison was added the name of Steinmetz, the great electrical engineer. Attracted by the fame of these names, there was a pilgrimage of electrical students from Sweden to the United States at the turn of the century, and I was among them.

Thus I soon found myself working in Schenectady. It gives me a great satisfaction to be able to say now after more than 40 years that I had not been chasing a rainbow but that I found almost immediately in the United States and in General Electric Company, all that I had hoped for in inspiration, opportunity, and friendly guidance. While I was still a student engineer I wished to try out some new ideas. Machinery was made available, and our chief engineer, E. W. Rice, who is remembered with admiration by all who knew him, found time to discuss the project and witness the tests. I also found that Doctor Steinmetz, whose reputation brought me to the United States and to Schenectady, was always accessible for discussion of new ideas.

This was the spirit I had hoped to find in America and the reason why I came here to stay, and not for a youthful adventure as my family in Sweden had hoped it would be. Some years later when it was my engineering assignment to design a-c railway motors, I was allowed to experiment at my own initiative with high-frequency alternators and other devices intended for telephoning across the ocean. The appropriations for this experimentation were approved by Mr. Rice personally and the objective was eventually realized.

This is just an example of the spirit of the leading industrial institutions. Similar testimony might be given for other electrical manufacturers and other industries. Much original work of high merit is done by independent inventers, but there are some lines of work which due to their character can be undertaken only by large industries. The typical American spirit of optimism towards invention prevailed largely until the depression in the 1930's. It was said then by many that we should have an inventers' holiday, because invention makes production so efficient that it creates unemployment. But then this war came, and the creative resources of industry were mobilized; scientists and teachers turned out by the thousands from the universities and have done a magnificient job of fighting the war with invention. But it is a paradox that it takes a war to permit this source of creative talent to function in its full and natural way. Some of our economists state convincingly, indeed much too convincingly, that the present pace of new development cannot continue because the Nation cannot afford to maintain it.

In a speech before the National Industrial Conference Board, 1944, Virgil Jordan made some impressive statements under the heading "Let Us Tell Them the Truth." I quote: "Never before have we been so self-conscious about postwar employment—war today is a public-works program turned upside down. That is why someone has said that war has become the main instrument of domestic policy, and, by a strange paradox, men pursue social or economic security by dropping high explosives on each other." He also quoted William James, the American philosopher, who racked his brains in the '90's to suggest what he called a moral equivalent of war and came out only with a sort of mid-Victorian version of WPA.

Quoting again from Mr. Jordan's speech: "Let us not pretend to them that for the first time in human history something has happened in America while they were gone that makes the words 'national planning' mean anything different than personal compulsion."

When viewed through these blue spectacles of the economist the world looks gloomy. Without questioning the soundness of the economic argument, many of us are inclined to feel that something has been left out, some social factor which perhaps does not belong in the realm of economics. If, on the other hand, we put on the rosy spectacles of the inventer, the world looks different. The creative talent is there. We have proved it during two wars. The engineers are eager to do their part in creating new industries. Conditions may after all not be so very different now from what they were in the early days of Edison. While William James racked his brains to find the moral equivalent of war, Edison had a different approach. He did something about it and founded the electrical industry. Then Marconi stepped in and started the radio industry. Is not this what the world needs—engineers who can create new industries? We cannot point to any one successor of Edison, but Edison's spirit is alive among all of us and is symbolized by the Edison Medal. This symbol and all it implies is held up as a guiding beacon, an object of faith for the engineering profession. It is also a challenge to the engineers of this generation, a challenge that we must accept and prove that our faith is the kind that can move mountains. When Edison brought out his system of electric lighting, it was an expensive luxury. But he was not discouraged by the fact that it could not compete in economy with gas lighting. He and his backers had the faith and courage to push his dream to realization and make out of it what he saw in his mind's eye and what we now know to be a fact.

Marconi had to come to England and America to get financial support for his invention, but nobody at that time imagined the magnitude of the industry that would develop from it. Let us hope that there will be in the future the same kind of willingness to take financial risks and that the history of the age of Edison will repeat itself. What right have we to say at this time that science and invention have been exhausted and that we are no longer able to create new industries? If the only work that we can see ahead of us is to do more efficiently and in greater volume the things we know how to do now, then we must also accept the sad but logical conclusions of the economists. Perhaps thousands of years from now science and invention will be exhausted and our civilization will be superseded by another, but the knowledge of engineering is only a couple of hundred years old, and we are at the apex of technical evolution, and with a man power of creative talent greater than any that has ever been assembled. This creative man power must not be held down to routine work lest the worst predictions will come true, and prophets of gloom prove right after all!

Science has made enormous progress during the war and has given us a wealth of new ideas to work with. In electrical engineering alone we can see a number of great possibilities. Edison gave us electric light; but some day we will be heating as well as cooling our houses by electric power; ships will be propelled with electric motors fed from coal-burning gas turbines; our railroads will be electrified, utilizing our undeveloped resources of waterpower.

Looking still further ahead, we may hope for the discovery of some entirely new sources of energy which will extend the use of electric power. Electronics, the new branch of the electrical industry, will be put to work to solve these problems. There are so many applications of electronics in both power and radio that I shall not even attempt to enumerate them. A new generation of electronic engineering has grown up and is ready and eager to turn from war work to peace work. They will revitalize the electrical industry with new experience, new tools, and new ideas.

Inventions will not solve all our social problems, but they will be an important factor as they have been in the past. Engineering contributes to the future. If the engineer really believes in the value of his contribution, the financier will believe in it too and support him as he has done in the past.

The Edison Medal is a symbol and a challenge that this shall come to pass and that the next generation of engineers shall live up to the traditions of Edison, Westinghouse, and Marconi. With this faith and hope I wish to express my deep-felt appreciation of the honor which has been conferred upon me and the company which I represent.

Electronics of the Mass Spectrometer

JOHN A. HIPPLE, DON J. GROVE W. M. HICKAM

THE suddenly developed need for high-quality aviation gasoline, synthetic rubber, explosives, and other important materials having a vital relation to the success of the war effort gave impetus to the task of finding improved means for quickly and accurately determining the purity of constituents forming a part of these products. For making these determinations such methods as fractional distillation and infrared and ultraviolet absorption have been employed with varying degrees of success, often in conjunction with one another. No single method provides the complete solution of the problem for all possess shortcomings, which has accelerated the search for other methods, particularly one that will facilitate making analyses of complex hydrocarbon mixtures. The mass spectrometer is a new and valuable method in the analysis of such problems.

In addition to its value in determining the purity of the compounds mentioned, the mass spectrometer has other important uses, and it might be well to summarize some of them here:

1. In all tracer work where stable isotopes are used (this method is practically the only available one).
2. For analysis of small traces of gas in a mixture.
3. In analyses where only a small sample of gas is available, as in the analysis of the residual gases in sealed-off electronic tubes.
4. In analyses requiring the continuous indication of changing composition during a process, as in the gas atmosphere of an annealing furnace.

The mass spectrometer, as the name implies, is an instrument in which ion streams of different masses can be separated and measured in a manner that permits both qualitative and quantitative measurement of the components of a gas mixture. It is essentially a high-vacuum tube into which the gas to be analyzed is admitted and ionized. By closely controlled electric and magnetic fields, the ions are caused to move through the tube so that each stream of ions of different mass can be focused successively on an exit slit at the end of the tube where they impinge upon a plate and give up their charge. This charge or current is amplified and measured by electric instruments. From the characteristics of these electrical readings the exact composition of the gas mixture is readily obtainable.

Essential substance of a paper presented at the National Electronics Conference, Chicago, Ill., October 5–7, 1944.

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The authors express appreciation for the work of their associates who have contributed to the development of the mass spectrometer.

The value of the mass spectrometer as an instrument for the quantitative and qualitative measurement of the components of gaseous mixtures is enhanced by a recording system which combines speed of response, accuracy, and extensive range. These have been attained by incorporating an automatic speed-up between peaks, an amplifier for currents as low as 10^{-14} ampere, an automatic range changer for off-scale peaks, and a nonlinear scale to overcome the limitations of a ten-inch chart.

Figure 1 is a schematic illustration of one type of mass-spectrometer tube, which will serve to illustrate the essential principles involved in mass spectrometers used today for routine analytical work. The tube is evacuated continuously by means of a diffusion pump, and the sample flows through the ion source continuously during the analysis. Electrons emitted from the filament are accelerated through the slits in the electron gun formed by plates 1 and 2, and the current in this electron beam is measured on electrode 3. The ions formed by the impact of the electrons on the gas molecules in the region below plate 4 are repelled by the slight positive voltage on this plate through the slit in 2. These ions, emerging from the slit in 2, are accelerated to plate 5 by the fairly high potential difference between 2 and 5. Conventionally, electrode 2 is of the order of 1,000 volts positive with respect to plate 5, which is at ground potential. The ions now pass into the analyzer portion of the tube, the internal surface of which is grounded to provide an effective electrostatic shield for the beam. The curved portion of the analyzer is situated between the pole pieces of the electromagnet; the field from this electromagnet deflects the ion beam, as indicated by the arrows. The radius of curvature of the ions is given by the following formula:

$$r^2 = \frac{m}{e}\,\frac{VC^2}{150\,H^2} \qquad (1)$$

r = radius in centimeters
m = mass in grams
e = charge in electrostatic units
V = accelerating voltage in volts
C = velocity of light in centimeters per second
H = field strength in oersteds

By appropriate adjustment of the fields, an ion of any desired m/e may be focused on the exit slit, 6, passing through this slit to the ion collector plate, 7. In order that the focus of the ion beam on the exit slit may be maintained, it is necessary that the ion accelerating voltage and the deflecting magnetic field be very carefully regulated. For an instrument designed to handle the usual analytical problems, the ion accelerating voltage should be maintained constant to at least one part in several thousand, and, as the magnetic field appears as a square term in equation 1, the regulation required for this is twice

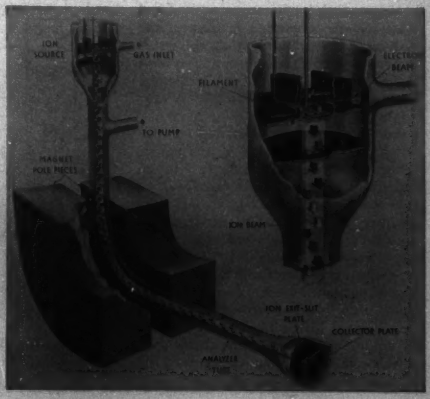


Figure 1. Schematic drawing of one type of mass-spectrometer tube used for routine analytical work

as great. The careful control required on the power supplies providing these fields may be obtained by means of conventional electronic regulators. Since the magnet employed with a tube using a deflection of 90 degrees is fairly small, it may be energized with a regulator of rather low power output. The maximum magnetic field required may be obtained with 110 milliamperes. The interrelations of the various components in the instrument are shown schematically in Figure 2, and the connections shown in Figure 3 provide the necessary correlation of the electron and ion beams.

Analysis of the amount of oxygen and nitrogen in air illustrates the operation of the mass spectrometer. Oxygen and nitrogen in precisely measured proportions are prepared and allowed to flow through the mass-spectrometer tube as indicated in Figure 2. Ions of nitrogen and oxygen enter the analyzer from the ion source. The fields are adjusted so that the nitrogen mass 28 is focused on the exit slit of the mass spectrometer,

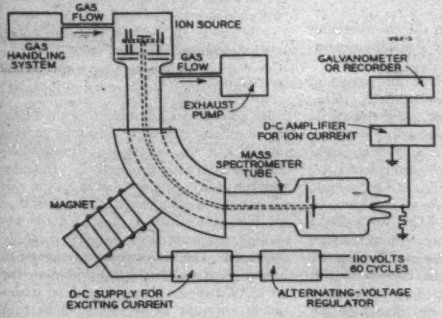


Figure 2. Detailed schematic diagram of mass spectrometer showing interrelation of components

and the current is measured. Since the oxygen mass 32 is heavier, it is not deflected so much by the magnetic field and is lost on the grounded interior of the analyzer. A readjustment of the fields permits the current corresponding to mass 32 to pass through the exit slit and be measured. The instrument thus is calibrated for nitrogen and oxygen in any proportions, and the quantitative determination of the composition of air passing through the mass spectrometer can be secured.

As previously described, the currents reaching the collector plate, 7, corresponding to the various masses are carefully measured. During this scanning of the spectrum it is essential that the electron current to plate 3 be kept very constant. This is done by using the current to plate 3 as a signal for controlling the heating current in the filament. The circuit used for this control is similar to that used for the control of the emission in ionization gauges.[1] Figure 4 shows the constancy of this electron current over a considerable period of time.

For effective use of the mass spectrometer a fast recording system is a necessity. The problem is that of obtaining a large amount of data in a very short time and accurately measuring currents which differ greatly in magnitude. A pen recording system was believed to be desirable, if it could meet these requirements. A brief review of recording systems which heretofore have been applied to the mass spectrometer would include primarily only those using a combination of light beam, mirror galvanometer, and photographic paper. Bleakney, Smith, Lozier, and Smith[3] have described a recording system of this general type for use in studies of the fundamental processes involved in the dissociation of molecules by electron impact. This was a dual system which recorded the ion current and electron current simultaneously, since no attempt was made to monitor the latter. A very wide chart was used in order that a considerable range of ion currents could be covered. The system was slow, since in this application high speed was of minor importance, and in order to record with a line of uniform density the intensity of the galvanometer light was increased manually when the spot moved rapidly across the chart. Washburn, Wiley, and Rock[4] have described a fast recording system employing the photographic method with four galvanometers of different sensitivities to span the range required.

A pen recording system has been tried using the same setup as required for the photographic method but with the replacement of the photographic detector by photoelectric cells mounted on a motor-driven carriage carrying a pen which follows the deflections of the light beam across a strip chart.[4] This method satisfactorily eliminated the photographic film, but the speed of response was too slow for application to the mass spectrometer, and the problem of extending the range was a difficult one.

The Speedomax recorder of the Leeds and Northrup Company has been made the basis of the recording system now to be described.[6] That recorder has lent itself nicely to adaptations for obtaining the speed of response, accuracy, and range mentioned earlier.

In order that the spectrum of masses may be swept across the exit slit of the mass-spectrometer tube and reach the ion collector plate, 7, of Figure 1, either the ion accelerating voltage V between plates 2 and 5 or the magnetic field must be varied continuously with the chart drive on the recorder. The question of which one of these is to be varied is a determining factor in the over-all design of the instrument. A consideration of equation 1 will show that, if the ion voltage be varied, the voltage range required will be very great to permit the scanning of a wide span of masses. Thus for a fixed magnetic field the equation involved is

$$\text{Mass} \times \text{voltage} = \text{constant} \qquad (2)$$

If mass 10 be focused on the entrance slit with 6,000 volts, it will require 600 volts for mass 100. This means that, in order to scan continuously through this range, it would be necessary to have 6,000 volts available, and the instrument would have to be designed and insulated for this high voltage. Furthermore, unless very much greater ion voltage is available, it would be necessary to shift the magnetic field to record below mass 10 and above mass 100. If the scanning be done by varying the magnetic field, the ion voltage may be kept fixed at 600 volts, and the entire mass range may be covered with a variation of the magnetic field alone. The mass spectrometer and its associated power supplies then may be designed for low-voltage operation.

The scanning circuit for the magnetic field is illustrated in Figure 5. With this circuit, the load on the regulated high-

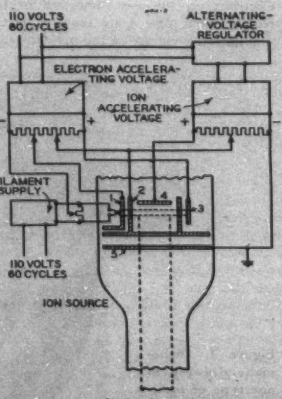


Figure 3. Detailed schematic diagram of ion source showing interrelation of components

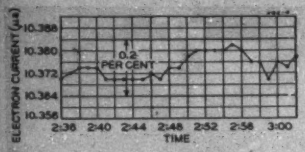


Figure 4. Plot of electron current as a function of time, indicating performance of electron-current regulator

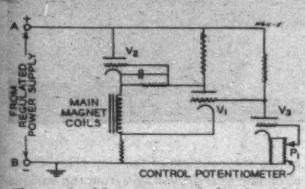
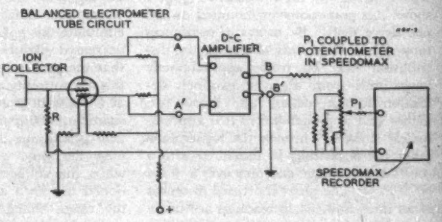


Figure 5. Magnet control circuit which makes possible a wide variation in magnet current with a single control, yet keeps nearly constant load on the power supply

voltage power supply may be kept constant within a few per cent, as the current through the coils of the magnet is varied from 10 to 110 milliamperes. The vacuum tubes V_1 and V_2 function as a series–parallel resistance control. As the scanning potentiometer P_1 is varied from one end to the other in a direction to decrease the current through the magnet, the plate-to-cathode resistance of V_1 decreases as that of V_2 increases, maintaining approximately a constant resistance between A and B. The potentiometer P_1 is mounted on the recorder and is driven by the same motor that drives the chart. In Figure 6 the recorder is shown with its top cover removed to illustrate this potentiometer.

To operate the recorder, an intermediate amplifier was required between the ion collector plate, 7, and the recorder input terminals, since the current to be measured could be as low as 10^{-14} ampere. The essential principles of the amplifier are shown schematically in Figure 7. The first stage is the conventional balanced circuit used with electrometer-tube amplifiers.[6] A balanced circuit of some kind is necessary in this first stage, because the voltage gain is actually less than one through the electrometer tube. This is followed by a high-gain d-c amplifier providing an output to the recorder at B-B'. By connecting point B to the bottom of the input resistor R, 100 per cent inverse feedback is obtained, so that the over-all voltage gain is unity and the input voltage at B-B' the same as the input voltage across the resistor R. This provides an amplifying system for the ion current which is faster than the recorder itself, which means that the recording time is limited only by the response time of the recorder. Since R is 2×10^{10} ohms, the input capacity to

Figure 7. Schematic diagram of the ion-current amplifier showing the various components and their relationships



the electrometer tube would cause a very slow response time as the time constant is several seconds; however, with the feedback system just described, the speed required for fast recording may be obtained. As the Speedomax is itself a null instrument, the use of an amplifier with 100 per cent negative feedback in conjunction with the Speedomax gives us an essentially null method of measuring ion currents with attendant freedom from the problems of linearity associated with deflection methods. This complete amplifier is operated entirely from the 60-cycle power line.

In order to increase further the speed of recording the spectrum, an automatic speed-up between peaks has been incorporated. A spectrum of a mixture composed of ethane, ethylene, and neon shown in Figure 8 illustrates the functioning of this device. This spectrum has been retouched for reproduction because the red ink used in the recorder does not photograph well. When the pen is on the base line between peaks, the masses are scanned at high speed, and hence the chart is moving rapidly. As the pen deflects off the base line to trace a peak contour, it trips a switch at the region indicated on the diagram and automatically slows down the system to insure that the pen will have time to record accurately the top of the peak, as this is the only information required for the analysis. Just before the pen has returned to the base line after recording the top of the peak, it again crosses the speed-change line and automatically returns the system to its original high-speed scanning.

With the system just described it is possible to obtain a spectrum very rapidly, but the problem of accurately recording the wide range of ion currents on a ten-inch chart is unchanged. This has been solved by the addition of two features: the first is the incorporation of a nonlinear scale, and the second is an automatic range change.

Figure 7 illustrates the method of obtaining the nonlinear scale. The motor which drives the pen upscale is coupled to the movable contact on potentiometer P_1,

Figure 6. The scanning potentiometer which operates the magnet control circuit is shown in this view of the top of the Speedomax with the protecting cover removed

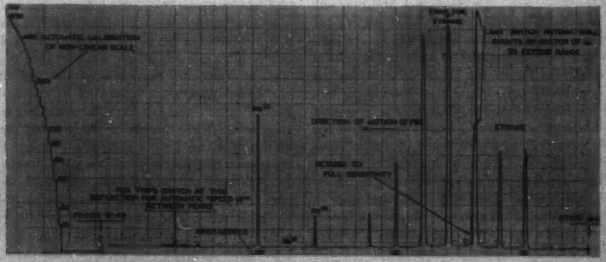

AUTOMATIC CALIBRATION OF NON-LINEAR SCALE
LIMIT SWITCH INTERRUPTS ARRETE OF MOTOR AT 10 DIVISIONS RANGE
DIRECTION OF MOTION OF PEN
ETHANE
RETURN TO FULL SENSITIVITY
PEN TRIPS SWITCH AT THIS DEFLECTION FOR AUTOMATIC SPEED UP BETWEEN PEAKS
PEAKS SLOW
SPEED UP

Figure 8. Spectrum of a mixture composed of ethane, ethylene, and neon illustrating the speed-up between peaks

This spectrum has been retouched to facilitate reproduction

Figure 9 (left). The potentiometer P_1 of Figure 5 is shown in position in this view of the back of the pen and chart carriage

Figure 10 (right). The synchronous motor and pickup coil for the mass marker are shown to illustrate the position of the generator relative to the magnet gap

which shunts the input signal. Figure 9 shows this potentiometer mounted on the pen drive shaft. By means of resistances tapped into P_1 at various points, the distribution may be made approximately logarithmic from about a two-inch deflection to ten inches; and below two inches as it approaches zero it is approximately linear. Through the logarithmic range the peaks may be measured with a constant percentage accuracy over a range of 20 to 1. The chart is divided in tenths of an inch, and, when readings are made to a fifth of a division, the accuracy is better than one per cent. To convert the measured deflection on this nonlinear scale to actual peak height, it is necessary to know the scale calibration. For this purpose an automatic scale calibration has been included. This appears at the one end of the chart in Figure 8. These steps show the pen deflection when known voltages are applied to the nonlinear system. The conversion from the nonlinear scale to a linear scale in measuring the charts has been found to be a simple process, as the distribution remains the same for many months; in fact, it is possible to measure a peak as soon as the pen has traced over its top without waiting for the rest of the spectrum to be scanned.

In case a peak is too large to be recorded by the system just described, the pen will hit a limit switch at the upper end of the chart, activating a relay whose contacts shunt the input to the recorder system at B-B' on Figure 7. Thus, if the input be shunted in this manner by a factor of ten, the range of current that may be recorded accurately will be 200 to 1 instead of the range of 20 to 1 mentioned in the previous paragraph. Of course, it would be possible to have a stepping-type limit switch at the upper end to shunt the input a number of times should an extreme range of ion currents or a need for higher accuracy require more scale expansion. In Figure 8 the mass 28 peak illustrates this shunting system. Although the recorder pen moves downscale very rapidly after hitting the shunting switch, there is a possibility that the top of a peak that will be just off scale on the first range would be missed. To eliminate this possibility the ion voltage is decreased slightly by an amount ΔV so that the peak top will not appear during this discontinuity. As all the peaks appear at a constant accelerating voltage of, for example, 600 volts when the magnetic field is scanning the masses, all the peaks have the same width in voltage. Thus when the voltage change ΔV just mentioned has been adjusted to take care of the range change discontinuity for one mass, there is no further adjustment required as ΔV is the same for all masses. When the pen approaches the region of the speed-up switch after tracing the peak contour at the reduced sensitivity, the shunt is removed, returning the recorder to full sensitivity, and the small additional voltage ΔV is removed from the ion gun. A close inspection of the mass 28 peak in Figure 8 will show the appearance of the peak contour as a result of the processes just described.

Although the method of scanning through the spectrum by varying the magnetic field has the advantages mentioned previously, there remains the difficulty of accurately identifying the masses of the peaks that appear on the chart. A measurement of the current energizing the magnet coils is of little help because of the hysteresis. For this reason a mass marker based on an actual measurement of the field in the gap of the magnet deflecting the ion beam becomes essential. For the mass marker incorporated in the recorder which has just been described, the magnetic field has been measured by spinning a coil in the gap of the magnet by means of a synchronous motor.[7] Leads from this coil are brought to a commutator, and the output from the brushes is carefully filtered. The output from this filter is then directly proportional to the magnetic field and may be used as a basis for a mass-marking circuit. Figure 10 shows the mass-marking generator in position. The principle of the mass-marking circuit is illustrated in Figure 11. The resistors across the contacts of the step relay C are so chosen that the voltages from the various taps can be made to correspond to the output voltage from the generator to mark preselected masses. Of course, for a given voltage on the ions a careful adjustment must be made initially with the variable resistance R. The operation of the mass-marking circuit is then as follows: as the magnetic field is decreased and approaches the value where, for illustration, mass 15 is focused on the exit slit of the mass spectrometer, the output from the generator G becomes equal to the voltage from the step relay C. The circuit A detects this balance and moves the contact C from 15 to the next step, 10, while an auxiliary relay and pen puts a mark on the chart. The voltage from G is now greater than that from C, but as the magnetic field is further decreased, the generator voltage becomes equal to the voltage from C when the magnetic field is the proper value for

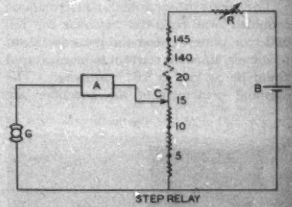


Figure 11. Schematic diagram of the essential features of the mass-marker circuit

focusing mass 10; at this instant the circuit A again detects the balance, shifting the contact C to 5 and again marking the chart. The step relay turns a pointer which indicates the mass corresponding to the last mark on the chart. With some refinements and the use of an add-and-subtract relay, this system has been made active in both directions—that is, with

either decreasing or increasing magnetic fields. The mass marks are indicated at the bottom of the chart in Figure 8.

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Grounding Principles and Practice

IV—System Grounding

W. R. BULLARD
MEMBER AIEE

Grounding of transmission and distribution systems is considered in this article, the fourth of five based on a series of lectures on the subject which was sponsored by the power and industrial group of the AIEE New York Section during the 1943–44 season. Purposes and methods of grounding at substations, along transmission lines, and in a-c open-wire overhead distribution systems are discussed.

THE SUBJECT of transmission- and distribution-system grounding is divided for convenience into three principal parts, substation grounding, transmission-system grounding, and distribution-system grounding, which will be taken up in that order.

SUBSTATION GROUNDING

The term substation is applied commonly to a great variety of electric stations. Therefore, for a clear understanding of the following it is necessary to keep in mind specifically the types of stations to which this discussion applies. They are: transmission step-up, step-down, and switching stations; distribution substations serving general-purpose primary distribution systems, and industrial substations of large size. Smaller industrial stations have grounding requirements generally similar to those of distribution transformer installations which are treated in the third part of this article. As the discussion proceeds it will be recognized that it is concerned particularly with stations of the outdoor type located in areas where transmission and distribution lines are overhead. However, most of the principles outlined apply equally well to indoor stations and those located in areas where lines are underground. The need for lightning protection in the latter type of station, of course, is generally not present.

Having defined the types of substations under consideration the purposes of grounding may be reviewed briefly as follows:

(*a*). Grounding for lightning and surge protection.

(*b*). System grounding to stabilize circuit potentials with respect to ground and to provide means of circuit relaying to clear ground faults.

(*c*). Grounding of non-current-carrying structures and parts and auxiliary low-voltage circuits, for safety to persons.

Grounding may be employed for one or more of the foregoing purposes in any particular substation. In the early beginnings of grounding practices, the feeling was prevalent that separate grounding facilities should be provided for each purpose. Thus lightning-protective equipment would be connected to one ground or set of grounds, the system ground connection would be made to another set, and so on. This not only resulted in undue expense but also the effectiveness of lightning-protective equipment was unnecessarily poor. Later it became generally recognized that interconnection of all grounds aids in securing maximum effectiveness, the conductivity of each ground supplementing that of the others in the interconnected group. In modern substation grounding practice, therefore, it is common to find either a single all-purpose ground bus, or two or more interconnected busses if the layout is such as to make this arrangement more convenient.

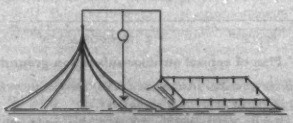

Figure 1. Point grounding versus distributed grounding

Grounding is an important feature of substation design and much care in obtaining an effective grounding system can be justified when it is considered that the substation is a place of energy concentration, a switching center upon which continuity of service may be dependent, the location of large and costly electric equipment, and the scene of frequent operating and maintenance work by company employees. If the station is attended, the element of personal safety is of still greater importance.

With the aim of a uniform or near uniform potential of earth surfaces in the area under consideration, well-distributed ground beds consisting of driven rods frequently provide the most efficient use of the money spent for grounding if they can be driven to effective depths without encountering rock or other obstructions. If practicable they should be driven into levels of permanent moisture. Where pile foundations are needed for structural reasons grounds have been made by attaching copper wire in grooves on one side of some of the piles to within two or three feet of the lower ends. These may be used as the sole method of grounding or in combination with other types of electrodes depending upon requirements.

In instances of dry soil or high earth resistivity from other causes, conductivity sometimes is improved by use of salt, char-

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coal, or other chemicals around the electrodes. In instances of very dry sandy soil or similar conditions of difficult grounding, deep wells have been sunk, with metal casing or immersed plates being used for the ground electrodes. In other instances of extremely difficult grounding directly at the substation site, better facilities have been found relatively near by, such as a stream or other body of water, and use has been made of such facilities by installing the ground bed at the needed distance from the station and extending the ground bus out to the ground bed. Where this is done care must be taken that the ground bed and associated connections do not constitute a high-potential hazard to persons, under fault conditions at the station.

Where ground beds of driven rods are used the most efficient arrangement is with a fair amount of separation between rods. This leads to the common practice of driving a series of rods around the outer perimeter of the station, supplemented by additional rods scattered through the station area at points of connection to lightning protective devices or other important equipment. The conductor interconnecting the rods forms a portion (in some cases the major portion) of the ground bus, and in the case of outdoor stations it may be buried several inches under the surface of the earth.

In thickly populated districts where substantial networks of underground metallic water pipes are available, the inherently low ground resistance of such networks may be made use of by direct connection from the ground bus. However, before using water pipes as the main source of grounding for large substations, conditions should be investigated to make certain that the water pipes have adequate size to carry maximum currents to which they may be subjected, and that the local resistance to ground is adequately low to avoid hazard from high potentials to water consumers in the immediate vicinity and to prevent local high potential gradients at the ground surface in the substation area and vicinity. With respect to the last mentioned consideration, connection to small pipes of high resistance may have the effect of "point" grounding as contrasted with distributed grounding consisting of a number of widely spaced ground electrodes of other types.

Figure 1 represents an attempt to show graphically a comparison of potential gradients at the ground surface for grounding with a single ground rod, and for grounding with a number of rods such as along a rectangular ring ground bus. The distances above ground surface of the various lines represent potentials in the ground at the corresponding points. Note the very steep gradients near the single rod, which might endanger persons or animals standing on the ground. The generator shown, of course, is purely pictorial.

The over-all requirements as to ohms resistance of a substation grounding system naturally depend upon the purposes for which the grounding is used and other re-

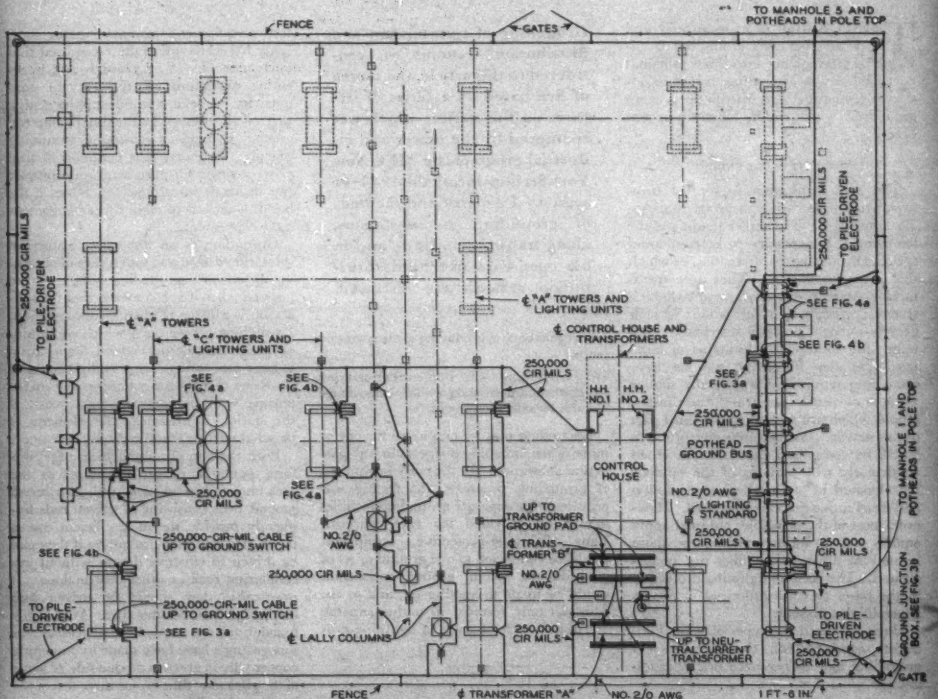

Figure 2. Plan of typical outdoor-substation ground-bus layout

Ground cables are buried in the ground at a minimum depth of one foot six inches
All copper cables and bars are tinned at points of connection
All electrical equipment, conduits, cable sheaths, structural steel, and so on, are permanently grounded
Ground resistance, for this installation was specified to be five ohms or less
All power-cable sheaths are bonded to ground cable in all manholes and a potheads

lated factors, such as voltage of station circuits, fault current required for relaying, impedance of circuits and station equipment, and the like. Lightning protection of station equipment by lightning arresters or spill gaps can be made largely independent of ground resistance by interconnection of the ground bus with non-current-carrying parts and circuit neutrals. Therefore, the requirements for conductivity to ground may be determined largely by the needs for system-neutral grounding, including relaying requirements. However, unless the grounding is adequate to avoid potentials on the ground bus, under fault conditions, that would be hazardous to the lives of persons working in and around the station, special precautions must be taken to equalize potentials between exposed structures and objects. This means solidly connecting all such structures (usually including the fence, if of metal) to the ground bus and also providing that any surface on which a person may be standing is substantially at the same potential as surrounding objects. In the case of outdoor stations this sometimes is accomplished by placing steel plates well connected to surrounding structures, switch handles, and the like, for operating personnel to stand upon in locations requiring specific operating duties. In other locations the same purpose of equalizing potentials may be accomplished by the use of buried grids of light conductors a few inches under the ground surface. In extreme cases such a grid may be used over the entire substation area. Also, sometimes it may be desirable to use a ground grid extending outside the fence for a few feet if the fence is of metal, in order to avoid high-potential hazard to persons standing on the ground outside the fence and touching the latter during a fault to ground.

Relay circuits, control circuits, and communication and metering circuits commonly associated with substations have low-voltage insulation and ordinarily are connected to the ground bus for removal of static potential, for protection against instrument-transformer failure, and for safety to persons handling or working with the low-voltage equipment. It is essential that large potential differences along the ground bus be avoided to prevent breakdown of the insulation of these circuits from conductor to non-current-carrying parts or from conductors of one type of low-voltage circuit to those of another. This fact and the need for keeping potential differences between any and all exposed parts low for safety to personnel justify a liberal size of ground bus to secure good conductivity, and emphasize the need for well-made grounding and bonding connections throughout.

The ground bus and associated conductors, aside from the question of voltage drop under fault conditions, also must be large enough to insure against burning off or burning open due to fault current. These considerations usually lead to the use of copper for the bus and its associated conductors, and to the use of brazed or clamped connections instead of soldered joints. Special attention should be given to the main loop of the grounding system and to all sections of the bus that may be called upon to handle heavy currents.

It is considered good practice to provide two or more paths to ground for each piece of apparatus that may receive heavy fault currents. The size of each conductor should be ample to carry maximum calculated fault current based upon all equipment in the station being in service and taking into account the number of transformers or other pieces of equipment having their neutrals grounded. When neutrals are grounded through resistors or reactors, consideration should be given to whether these current-limiting devices are provided with by-pass switches.

Liberal size of the grounding bus usually is considered a good investment. The cost is relatively small, and the security afforded is great. The matter of personal safety is of especial importance as there have been a fair number of fatal accidents due to high potential differences between exposed parts during line-to-ground faults.

If the station is outdoor type and the ground bus is buried, the use of copper raises a question as to possible corrosion of the station structure footings because of the electrolytic couple created by the copper and the zinc coating of the structural steel. Because the station footings usually have concrete surrounding the steel the matter may not be of great importance in usual cases.

One influence of modern knowledge and thinking on substation grounding practices that is worthy of special note is that connections from lightning-protective devices to ground bus are now made as short as practicable and such devices are located as near as practicable to one or more of the ground electrodes. In other words, the path to ground for lightning and other surges is made just as short as practicable.

Figure 2 is the general ground-bus layout of a 110/13-kv switching and transformer substation, outdoor type. Note the ring bus and the cross busses of buried copper conductor. Also note the grids at switch operating points for safety of personnel. The substation fence, which is well connected to the bus, is barely visible close to the outer loop.

Figure 3 shows a bolted connection, pile ground, and grid detail of the substation ground system shown in Figure 2.

Figure 4 shows additional detail of the ground bus shown in Figure 2. This shows bolted connections to steel work and a vertical cross section of one of the grids designed to provide safety to personnel when operating switches and the like.

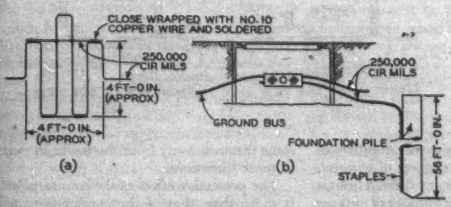

Figure 3. Ground-bus detail

(a). Potential-equalizing grid, buried six inches below grade in front of air-break-switch operating arms

(b). Bolted connection and pile ground electrode

TRANSMISSION-SYSTEM GROUNDING

The grounding of transmission lines will be considered from the standpoint of grounding along the lines, not at the terminals. The latter has to do with substation grounding and has been dealt with in the preceding section. Except for grounding of cable sheaths in connection with underground transmission, or rare cases of multigrounding of neutrals of such few transmission circuits as have neutrals, grounding along transmission lines has to do almost solely with lightning protection. The following discussion therefore will be confined to grounding along overhead lines for purposes of lightning protection.

Throughout this discussion of transmission-system grounding the term ground resistance refers to impulse resistance, which tests have shown to be in general somewhat lower than resistance at power frequency.

As an aid to clarity, it is desirable to review the elementary principles of lightning protection of transmission circuits. The primary purpose of such protection is to improve service continuity by minimizing flashovers and resulting circuit tripouts. The technique of lightning protection has advanced to the point where practically any degree of immunity from service interruption due to lightning can be secured, the limitation being the cost of protection as justified by the benefits gained. Aside from the use of Petersen coils applied at line terminals and therefore making use of substation grounds, there are two principal forms of lightning protection for transmission lines, namely, drainage of surges from the conductors by expulsion gaps, and shielding of conductors by overhead ground wires.

Expulsion gaps may be classed as a special form of valve-type lightning arrester and are connected (with external air gap) so as to bridge the insulation to be protected. They are intended to limit surge potential to values below insulation flashover and at the same time provide a path

to ground for the surge current. If the gaps are installed at every structure the latter function is auxiliary to the main function of preventing flashovers and does not require low-resistance ground connections. This freedom from dependence upon ground resistance is an important feature of expulsion gaps and provides for them a particular field of usefulness in situations where grounding conditions are unusually difficult. Thus (except for a special application mentioned further on) where expulsion gaps are used, simple and low-cost types of grounds usually are sufficient, such as the normal footing resistance of steel towers, pole-butt-wrapped grounds, or single driven rods in the case of wooden structures. Expulsion gaps are installed in sets numbering one, two, three, or four units per structure. In the simplest form of connections, one terminal of each gap is connected to the ground lead or to the tower. The other terminal forms one electrode of an air gap to the line conductor. Sets of expulsion gaps may be installed at each line structure, or at every other structure, or at even greater spacings, depending upon the degree of immunity from flashover it is desired to secure. However, as the spacing is increased, ground resistance plays an increasingly important part and expense may be incurred for providing low resistance.

A special type of expulsion-gap application makes use of one of the line conductors as an overhead ground wire in effect and permits the use of only one gap per installation. For this purpose the line conductor so used must be elevated above the other conductors, for example as with triangular spacing. Lightning striking the upper conductor passes through an air gap to the expulsion gap, and thence to the ground lead or tower. In this type of protection the ground resistance is important and is governed by the principles of ground-wire protection which are to be discussed later.

The most generally used form of protection is that of shielding by overhead ground wires. Such ground wires paralleling the line conductors are supported at a higher level than the conductors and spaced from them in such relation that the chances of a stroke of lightning contacting the conductors are minimized, the ground wire or wires taking the stroke instead. Rules for designing geometric configurations of conductors and ground wires to accomplish this purpose have been worked out from experience and laboratory tests. Whether one wire or two is used is a matter of selecting the most efficient design for a given type of line.

The ground wires are connected to earth at intervals along the line, usually at each supporting structure, and the part this grounding plays in the protective scheme is very important. For purposes of explanation a line supported on steel towers and having one ground wire will be assumed, and it is well to remember that this discussion deals with direct lightning strokes since it has been found by field tests over a period of years that practically all flashovers resulting from lightning on 66-kv and higher voltage lines are caused by direct strokes.

When lightning strikes the ground wire or the tower itself the tower-top potential is raised many thousands or even millions of volts above ground while the line conductors, relatively speaking, stay at practically zero potential. If the ground resistance is high the chances are very great that there will be flashovers from tower to line conductors followed by a flow of power current, and tripping of the line. However, if the tower is well grounded its potential rise will be limited to a value determined by surge current and ground resistance, and if there is proper co-ordination between ground resistance and striking distance across insulators or directly to conductors through the air, line flashover will be prevented.

This is a very simplified explanation of the part that grounding plays. The actual mechanism of development of potential between tower and conductors is complicated by the surge impedances of the ground wire and the tower, by reflections of the surge waves in the tower and along the ground wire to adjacent towers, and by the surge coupling between ground wire and conductors. However, all of this has been worked out to a fair degree and practical formulas developed so that performance can be reasonably well predicted for any given set of conditions. Knowing the frequency of lightning storms in a given area, and having established data giving approximate percentages of number of strokes having various degrees of severity, lines can be designed for any desired limitation on the approximate number of outages per year, the benefits gained being balanced against the cost of the protection. For example, if a line is designed to prevent flashover for all strokes of 80,000 amperes and less, about 95 per cent of strokes will be rendered harmless, the remaining 5 per cent perhaps causing flashover.

For a given protective level, and a given number and position of ground wires, protective design becomes a matter of co-ordinating ground resistance with line insulation, the latter being represented by the porcelain insulators in the case of a steel-tower line. Span length also is an important factor, but in general for a given span length the insulation must be proportional to the ground resistance at individual towers or vice versa. However, insulation is relatively costly, particularly since the dimensions and consequent cost of the towers themselves is influenced by the amount of porcelain insulation provided. Therefore, it usually is found less costly to decrease ground resistance than to increase line insulation for purposes of lightning protection, the insulation level then being determined by the normal line switching surges, and ground resistance being determined by the desired level of lightning protection.

The footings of steel transmission towers are in contact with soil and provide a certain amount of grounding. But on the foregoing basis of design the ground resistance of tower footings seldom is sufficiently low to provide substantial immunity from line flashover as a result of lightning. Therefore, supplementary means of grounding usually must be used. This may take the form of driven rods in locations where permanent moisture can be reached by the rods. The rods may be from 10 to 50 feet long and are driven around the base of the tower. In accordance with the principle that good separation must be maintained between electrodes to obtain conductivity the rods should be kept well away from the underground sections of the tower legs.

In situations involving dry soil, rock near the surface, or other factors preventing efficient use of driven rods, the counterpoise may be used instead. The counterpoise consists of one or more bare conductors buried a short distance beneath the surface of the ground and extending for some distance away from the tower in two or more directions.

The protective effect of the counterpoise is more than that of the conductivity to ground which it affords. Initially, when the surge reaches it, each wire behaves like a surge impedance of 150 to 200 ohms. Following the initial instant this impedance rapidly decreases, until it reaches the actual ohmic resistance to ground, the time taken for it to reach this resistance being related to the length of the counterpoise. In the flashover characteristics of insulators, time is an element, as well as magnitude of surge potential. The quicker the potential is limited or reduced, the more effective will be the measures taken to prevent flashover. Thus for a given total length of counterpoise conductor, the protection afforded will be somewhat more effective if the length is expended in several

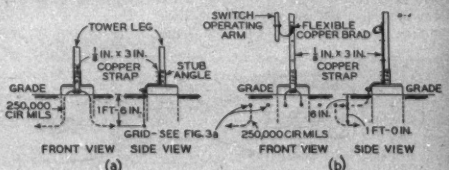

Figure 4. Method of grounding tower legs

(a). Towers without switch-operating arms

(b). Towers with switch-operating arms

wires radiating from the tower than if installed as a single stretch of wire. The more widely separated the wires are the more effective they will be as independent elements of the counterpoise system, and since it is found that the gain to be realized from more than four wires is not great, it might be concluded on first thought that an ideal arrangement would be four radial wires equally spaced from each other. However, there are factors other than the geometry and electrical efficiency to be considered. Questions of right-of-way frequently make impracticable the use of counterpoise wires at right angles to the line. Discontinuities, that is "loose ends" of the counterpoise wires, offer possibilities of high potential gradients along the ground surface under surge or fault conditions. These and other considerations make popular the use of continuous counterpoise wires parallel to the line, sometimes a single wire in the center of the right-of-way, sometimes two, one at each side of the right-of-way, depending upon the degree of protection required.

The effectiveness of counterpoises is found to be generally independent of the conductor diameter and of whether the wires are of copper or of steel. Therefore, the selection of the size of wire may be governed largely by mechanical considerations, and selection of the type of wire may be governed largely by questions of durability. Copper wire buried in the ground naturally may be considered more resistant to corrosion than galvanized steel, however, the latter possesses the advantage of avoiding an electrolytic couple that might tend to shorten the life of the tower footings. Such a couple can be avoided even with copper wires by the introduction of a short air gap instead of direct connection to the tower.

The foregoing discussion of ground wires and related grounding has been limited to steel-tower lines. Overhead ground wires may be used on wooden-structure lines, and the same principles of grounding apply except that the insulation can be greatly augmented by the surge insulation value of the wood structure. For example, one foot of wood is considered roughly equivalent to one suspension-insulator unit. Butt-wrapped grounds on wood poles are generally equivalent to one ground rod driven to the same depth.

Figure 5 shows a wood H-frame structure supporting a 154-kv line, with two overhead ground wires suspended at the ends of a steel crossarm at the pole tops. Height of the ground wires above and their offset from conductors insure that practically all lightning strokes will contact the ground wires and not the conductors. Ground leads down each pole connect to two butt-wrapped grounds tied together by an underground connection. The impulse insulation of the insulators plus wood crossarms is slightly greater than the flashover value through air between conductor and ground wire. With ground

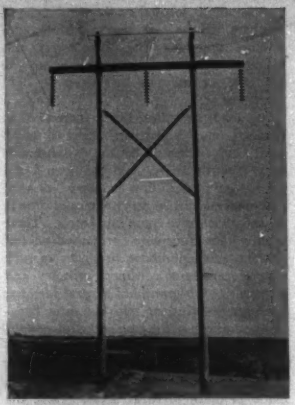

Figure 5. Wood H-frame structure supporting a 154-kv line, with two overhead ground wires suspended at the ends of a steel crossarm at the pole tops

resistance at the base of each structure amounting to 20 ohms or less, and based on commonly accepted data and lightning-propagation theory, only about three or four per cent of all strokes making contact with the ground wires result in voltage at the tower top sufficient to cause flashover between ground wire and conductor.

DISTRIBUTION-SYSTEM GROUNDING

The following discussion will be confined to a-c systems since they constitute the great bulk of distribution systems. It also will be limited principally to open-wire overhead systems, although many of the statements will be recognized as equally applicable to underground distribution.

The purposes of grounding in a-c distribution systems are in essence similar to those of grounding in substations which were listed in the first part of this article. However, in distribution systems, the matter of safety to persons looms large as a governing factor since it is through these systems that electric service is brought into the premises of the ultimate users. Grounding is an important factor in providing safety to the public in its use of the service—safety from overpotentials and safety by virtue of a stabilized relation of service potentials to ground. Safety to private and public property from fires of electrical origin also is dependent to some extent on the grounding of low-voltage distribution circuits. Grounding of fixtures, exposed non-current-carrying parts of wiring systems, and certain types of utilization equipment in consumers premises is a related aspect of safety to the public.

Grounding of distribution primary circuits has two principal purposes, stabilizing circuit potentials with respect to ground to avoid overstressing insulation, and providing a path for ground faults to aid in the operation of overcurrent devices and secure prompt disconnection under fault conditions. This latter function plays an important part in providing safety to the public because, in such instances as crosses between primary and secondary circuits and breakdown of insulation in transformers, the more rapidly the primary circuit is disconnected the less opportunity there is for the development of hazards to life and property.

Lightning protection in distribution systems differs appreciably from that of transmission lines as described in the preceding section. Distribution-system insulation levels are inherently low and it is not economically practicable to build up an effective system of shielding from direct lightning strokes such as described in the discussion of overhead ground wires for transmission lines. A certain amount of line tripouts from lightning, including direct strokes and other surges of relatively high magnitude, are accepted as a matter of course and service reliability is secured through the use of automatic-reclosing circuit breakers, duplication of circuits in some cases, and other measures that minimize the effects of circuit tripouts, rather than prevent them. Direct lightning protection in overhead distribution systems is largely limited to prevention of insulation failure in transformers and other equipment where repair or replacement is costly and time consuming. The forms of protection most commonly used are valve-type arresters, expulsion gaps, and open-spill gaps.

As in substation practice, early distribution-system grounding practice commonly provided separate grounding facilities for each grounding function. But the modern trend has been strongly toward pooling all grounding facilities and making use of their combined effectiveness for all purposes. Generally speaking not only does such practice aid in securing low ground resistance thereby making best use of money and effort spent in grounding, but also interconnection of various grounded circuits and objects tends to equalize potentials between them under fault or other abnormal conditions, thereby improving safety.

Multigrounding of secondary-circuit neutrals became common early in the development of grounded a-c distribution systems. Individual grounds at transformers, and at services, interconnected through the circuit neutral, and sometimes supplemented by grounds at other locations, constitute the essence of multigrounded secondary neutrals. The effectiveness of the grounding is greatly increased by connecting the neutral conductors to form a network where configuration of the system is such that this can be done readily.

Multigrounding of primary neutrals developed more slowly but came into common use with the development of 2,400–4,160-volt four-wire grounded-neutral sys-

tems. Soon thereafter as a logical step, in line with the modern trend toward pooling of grounding facilities, the multigrounded common primary and secondary neutral came into use. In addition to aiding grounding efficiency, it has the advantage of requiring only one neutral wire instead of two, not only saving expense and material but also aiding in relieving conductor congestion.

In overhead practice the common neutral usually is located at the same general level on the pole as the secondary conductors and may be completely uninsulated, that is, clamped directly to the pole, or may be supported on light insulators.

As load densities have increased in modern times and distribution distances have been increased by the expansion of rural electrification, need has been found for higher distribution primary voltages, and overhead primary systems operating at 11 and 13 kv have come into being. These usually are four-wire grounded-neutral systems or single-phase branches of such systems, and the common primary and secondary multigrounded neutral idea has been applied to them with the same benefits that accrue in the case of the lower voltages. While there are examples of extensive systems of this higher-voltage type in urban areas, most extensive use has been made of them in rural areas. Here the final branches serving individual farm customers may be single-phase lines consisting of one insulated and one multigrounded conductor, secondary mains usually being absent, and customers being served through individual transformers.

Whereas in urban areas multigrounded neutral networks may be continuous over the majority of the territory served and may involve hundreds of thousands or even millions of individual grounds, in rural areas connection in networks is not often practicable and grounds are spaced more widely. Also, water pipes used as grounding means, so effective in urban areas, generally are lacking in rural areas. Secondary mains frequently are not present, customers being served through individual transformers. In rural areas, therefore, all available means of making the grounding system really effective are needed. Use of the multigrounded common neutral had its beginning chiefly in urban areas, and the practice of tying in secondary grounds to the primary neutral in rural areas was approached with some hesitation, there being a feeling that this close association of primary and secondary circuits should not be practiced in any except those situations which provided conditions of very low ground resistance. It was realized, however, that accidental crosses between primary and secondary conductors, occasional breakdown between primary and secondary windings of transformers, flashovers of transformer bushings, and the like could not be prevented, and that the more effective the grounding system, the greater the safety under such occurrences. Therefore, the common-neutral idea was applied in rural areas, cautiously at first but more confidently as experience with its use was gained, until now the practice is widespread and commonplace. Where secondary mains are not present the term "common neutral" means that the grounded secondary neutrals of transformers are connected to the multigrounded primary neutral.

The full extent of the effectiveness of multigrounding of neutral conductors is not appreciated by many engineers. Studies have shown in some situations that even though pole-butt grounds may have considerably higher resistance than rods driven to a greater depth, the same amount of money spent for pole-butt grounds instead of for driven grounds may give lower over-all ground resistance for a multigrounded neutral. A larger number of butt grounds must be used but the cost per ground is considerably less. By "pole-butt ground" is meant a spiral of wire around the butt with perhaps a pancake at the bottom. Scrap wire can be used for this purpose, but, of course, such grounds must be installed at the time the poles are set. The foregoing statement should not be taken to indicate a general recommendation for pole-butt grounds, since there may be conditions of very dry soil down to depths well below the ground surface, for which they would not be effective.

Multigrounding is also effective in reducing the impedance of the neutral conductor and improving voltage regulation in a circuit in which the neutral carries some current. Consider a neutral conductor of an overhead open-wire circuit, grounded at numerous equally spaced points along its length, each ground having the same resistance. Neutral current from the source end of the circuit will flow only in the neutral conductor until the first ground is reached, where a part of it will escape to the ground. At the next ground more will escape, and so on until, if the line is long enough, a stable division between neutral-conductor current and ground current will be reached, determined largely by electromagnetic effects. At the load end the process is repeated in reverse order. At each end of the line a plot of current in the neutral conductor versus distance along the circuit takes the form of a hyperbola. The

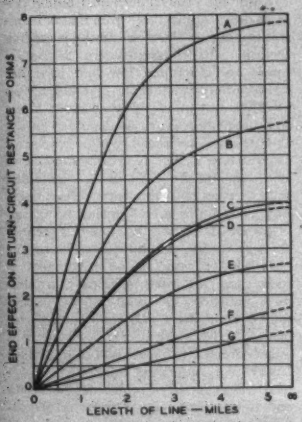

Figure 6. End effect on return-circuit resistance of multigrounded neutrals for the condition where average resistance of individual grounds divided by number of grounds per mile equals 20

A—Number 8 solid *D—Number 4 solid*
B—Number 6 solid *E—Number 2 stranded*
C—Number 4 stranded *F—Number 2/0 stranded*
G—Number 4/0 stranded
All conductors copper; sizes in American Wire Gauge

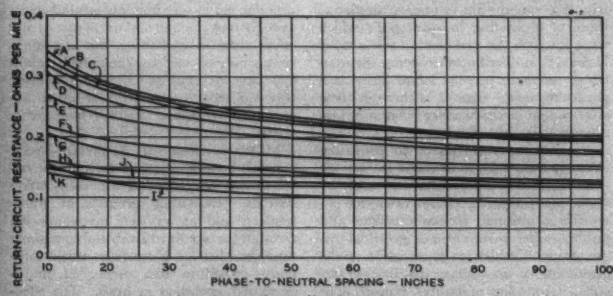

Figure 7. Return-circuit resistance per mile of multigrounded neutrals for zero-resistance grounds

A—Number 4 stranded copper
B—Number 4 solid copper
C—Number 6 solid copper
D—Number 2 stranded copper
E—Number 8 solid copper
F—Number 10 solid copper
G—Number 2/0 stranded copper
H—Number 4 solid steel
I—Number 4/0 stranded copper
J—Number 6 solid steel
K—Number 8 solid steel
Copper-wire sizes in American Wire Gauge; steel-wire sizes in Birmingham Wire Gauge

total effective neutral impedance is made up of two end effects which are dependent upon this hyperbolic decay of current in the neutral, and of another component that is uniform from point to point along the line and corresponds to the division of current where it becomes stabilized at some distance from the ends.

The following comparison illustrates the effectiveness of multigrounding in reducing impedance. The figures are for a three-phase four-wire line five miles long with number 6 American Wire Gauge hard-drawn copper conductors for the phase wires carrying a single-phase load of ten amperes line to neutral.

Neutral Conductor	Voltage Drop in Per Cent of Sending End (7,200 Volts)
Number 6 American Wire Gauge copper ungrounded	3.63
Number 6 Birmingham Wire Gauge steel multigrounded	2.61
Number 6 American Wire Gauge copper multigrounded	2.29

Figure 6 shows end effect on return-circuit resistance of multigrounded neutrals for grounding conditions such that the ohms per ground divided by number of grounds per mile equals 20. The curves represent that portion of return-circuit resistance caused by the varying amounts of current in the neutral conductor and in the ground at various points near the end of a uniformly grounded neutral. The value at the flat portion of the curve represents rather closely the resistance to ground that would be measured at one end of a very long neutral. For such a long neutral the total return-circuit resistance is obtained by taking two of these maximum values, one for each end, adding them together, and adding to this sum the value from Figure 7, corresponding to the same size of conductor, after having multiplied this latter value by the length of circuit in miles.

Figure 7 shows return-circuit resistance of multigrounded neutrals for zero-resistance grounds. This is the unit resistance per mile corresponding to current conditions in the middle portions of long multigrounded neutrals. Combined with the end effects shown in Figure 6 it can be used to determine the over-all resistance of the return circuit consisting of neutral conductor and earth in parallel.

Connection of effectively grounded guys to the multigrounded neutral constitutes extension of the principle of multigrounding, and results in reducing ground impedance of both the neutral and the guy. Therefore, this practice is often used instead of inserting insulators in the guys, under conditions where National Electrical Code requirements permit.

As stated previously, direct protection from lightning in overhead distribution systems is largely limited to prevention of insulation failure in transformers and other equipment where repair or replacement is costly and time consuming. The distribution transformer, of course, is the piece of equipment most frequently involved. Here again by pooling ground facilities greatest effectiveness is secured. During a period of a number of years of extensive field observation it was shown that if the ground lead of a lightning-protective device protecting the primary side of a transformer be connected to the secondary neutral (or better still to a common primary and secondary neutral) the quality of the protection provided is greatly increased. This, of course, is because the protective device then bridges directly the main portion of the insulation to be protected. But in addition grounding is improved by the addition of the lightning-arrester ground to the common grounding facilities. It is small wonder then that this interconnection has become a common feature of modern practice. There are several varieties of actual ground connections, some of them involving the use of spill gaps in the ground leads in lieu of direct connection. The most effective form of connection purely from the standpoint of lightning protection is one in which primary and secondary neutral, lightning-protective device, and transformer tank all are connected together and to ground. However, in some situations where it is desired to use the insulating value of the wood pole as a measure of safety to workmen, it is preferred not to ground the tank directly. In such cases a gap may be used between the tank and the ground connection. In other cases, as for instance; where primary and secondary neutrals are not made common, gaps may be inserted between the lightning protective device and either or both of the two neutrals. These various arrangements are shown diagrammatically in Figure 8.

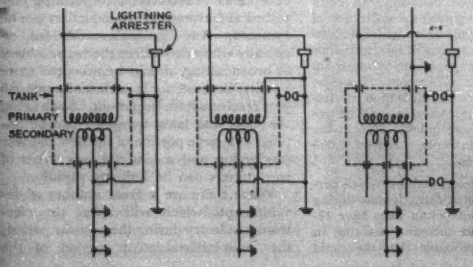

Figure 8. Lightning - protection connections for distribution transformers

It will be gathered from the foregoing that in distribution systems grounds are to be found at transformers and other equipment, serving purposes of circuit neutral grounding, and lightning protection; also as pole-butt grounds on poles other than those that carry transformers and the like. In addition there are neutral grounds at services. Ground electrodes may be of various kinds, direct connected to continuous underground water-piping systems being preferred, driven grounds and pole-butt grounds probably being next in order of extent of use. Generally speaking, by employing the best available means conveniently at hand for making individual grounds, and by making best use of the principle of pooling ground facilities, adequate safety is provided. The chief aims usually kept in view are:

1. Low over-all ground resistance to:
   (a). Avoid excessive overpotentials in case of faults between primary and secondary circuits. Maximum potentials can be calculated from available maximum fault currents to ground and over-all ground resistance.
   (b). Provide for positive operation of overcurrent devices in case of faults to ground. Under many conditions this may be more important than (a).
2. Avoidance of large potential differences between adjacent objects or circuits at locations where persons may be exposed to them. Frequently this condition can be met best by interconnection of the objects or grounded conductors involved.
3. Provision of conductors adequate to carry all ground currents likely to be involved, without burning open, and without excessive heating in locations where fires might result.

In consumers' premises, grounding of exposed metallic parts of wiring systems and of some types of utilization equipment is practiced for safety. The National Electrical Code deals in detail with such grounding. Important as it is as a safety measure, grounding is not always the only effective method of providing personal safety. Insulation is an alternative and in some cases may be preferable. For example, one of the most common causes of injury to persons from electric shock is the handling of portable trouble lamps or hand lamps under conditions where good contact is made with grounded surfaces by other parts of the body. If the lamp has a metallic shell poorly insulated from the current-carrying parts the results sometimes are fatal. Grounding of the lamp-socket shell may not be fully effective as a remedy since it is difficult to insure the effectiveness of such grounding where it has to be supplied through a flexible cord that may be subjected to much abuse. A simple and quite effective measure is the use of an insulating covering for the shell, or a shell of insulating material. This is only one example. There are others, and, in providing for safety, grounding should not always be considered to be a complete and absolutely indispensable measure.

XII—Developments in Radio and Television

W. R. G. BAKER
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If electronic progress follows the pattern set after World War I, the next decade will see the expansion of techniques nurtured by military need: frequency modulation, television, facsimile, and radar. Economic considerations, however, probably will set the rate and limit of their expansion.

THE PRESENT SYSTEM of sound broadcasting is the result of certain tools and techniques, the development of which was accelerated greatly by the communication demands of World War I. As a result of this scientific development, after the few years required for the reduction of these military tools and techniques to commercial practice, there began the commercialization of sound broadcasting based on amplitude modulation.

In surveying the history of the technical development of sound broadcasting, it is to be noted that there was continuous stimulation from technical advances up to the early 1930's. Also it must be noted that these improvements were, to a large extent, the result of the extension and refinement of the original tools and techniques. During the past few years, in fact up to a time just prior to World War II, the technical advances in sound broadcasting were of secondary importance. It appears as though the momentum gained through the original technical advances had been dissipated by the late 1930's.

In considering the expected developments in radio and television during the approaching postwar period, perhaps we should examine first the technical advances which have taken place during World War II. We may find that history repeats itself and that we have available new tools and techniques which will determine the probable trend in the growth of the new and the extension and expansion of the existing mass-entertainment businesses.

Considering only such technical facts as may be discussed and recognizing that there exists a mass of technical information which has not been released to the public, we can perceive certain important trends.

The factors to be noted are as follows:

1. Prior to World War II the utilization of the frequency spectrum for commercial radio and mass-entertainment purposes was for technical reasons restricted to frequencies under 100 megacycles. As a result of the technical advances fostered by World War II, certain services now employ frequencies as high as 1,000 megacycles, and some work has been done at 3,000 megacycles. This means that the utilization of the common denominator of all radio and television services, that is, the frequency spectrum, has been opened up by a ratio of 30 to 1.

2. We know that World War I produced sound broadcasting and greatly extended radiotelegraphy through electronic means, that is, by the electron tube. World War II has resulted in the development of a new system for the transfer of intelligence also based on electronics, namely, radar. Although practically all technical information pertaining to radar is still restricted for reasons of security, it is no secret that the tools and techniques evolved for its wartime utilization will have a direct effect on the mass-entertainment services during the postwar period.

3. Tools and techniques have been developed, which when converted to commercial practice will permit the utilization of the frequency spectrum up to perhaps 3,000 megacycles. How long it will take to reduce these tools and techniques to commercial practice is a very uncertain factor. However, it is apparent that the utilization of frequencies under 500 megacycles will be accomplished much more quickly than in the higher range, for example, between 2,000 and 3,000 megacycles.

4. An important factor, and one which perhaps is not appreciated fully, is that during the war thousands of young men have received a fairly good technical training in electronics. It is probable that the rapid commercial development of television would be retarded, if these trained men were not available for the engineering, marketing, and production of television equipment.

5. Before the war a number of components of major importance in television were not in mass production, therefore costs were high. War production has required mass production of many of these components which may result in appreciably lower costs during the postwar period. Probably one of the outstanding items in this category is the cathode-ray tube. In its case, standardization and mechanization of manufacturing processes should be reflected in important reductions in cost.

6. There is another factor which, though not strictly a technical one, does have a bearing on the postwar course of radio and television. This factor is obsolescence; not so much obsolescence of the sound-broadcasting transmitter equipment, although even here new methods have resulted in the more efficient generation of high-frequency power, but, particularly, obsolescence of the broadcast receiving sets in the homes of consumers.

The growth of amplitude-modulation sound broadcasting in the United States up to World War II is indicated by the fact that there are in operation about 900 broadcast transmitters, four nation-wide networks, and approximately 38 regional networks and group-operated stations. These transmitters serve perhaps 60,000,000 broadcast receivers.

It is obvious that during World War II obsolescence, particularly as applied to broadcast receivers, is working in favor of acceptance of receivers incorporating new technical features when production can be resumed. Any changes or additions, especially when they affect the entire system of broadcasting, should be accepted more readily, because, for a period of years, no new receivers have been built. Such being the case, the latest advances can be applied to a large portion of the new receiver production and a load for new types of transmitters can be built up rapidly.

While there are a great number of developments which will affect the electronics industry during the postwar period, the mass-entertainment section of the

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Industry will be by far the most important from the viewpoints of creating jobs and total dollar volume. The truth of this is evidenced by the fact that just prior to the present war sound broadcasting in all of its phases represented an annual volume of over $1,000,000,000.

Keeping in mind the six points previously listed, we shall consider the postwar developments in sound broadcasting and television.

Frequency modulation is a new system of sound broadcasting. Its present position in the frequency spectrum is from 42 to 50 megacycles. It is quite probable that after the war the upper frequency limit may be raised.

Frequency modulation is practically free from static and, in addition, suppresses other interfering noises. With amplitude-modulation broadcasting, the desired signal must be about 100 times as strong as the interference, if clear reception is to be obtained. With frequency modulation, the desired signal need be but twice as strong as the unwanted signal. In other words, for good clear reception at a given location, a standard broadcasting signal must be at least 50 times as strong as the frequency-modulation signal.

In terms of power, this means that it takes some 2,000 times as much power at a standard broadcasting station to deliver clear reception at a given receiver as it would for a frequency-modulation station operating on the same frequency at the same place.

Standard radiobroadcasting is more powerful at night than in the daytime. This fact results in interference at the perimeter areas of standard stations operating on the same frequency—particularly at night. With frequency-modulation broadcasting, on the other hand, operating on high-frequency channels, the radio waves travel outward in all directions to a distance two or three times the line of sight, perhaps as far as 100 miles under some conditions, and have about the same coverage areas day and night.

Suppose, for example, there are two 250-watt stations: one a standard broadcasting station operating on the 1,400-kilocycle channel, and the other a frequency-modulation station. At 250-watts power, the standard broadcasting station's daylight range might conceivably be 13 miles. At night, however, it would be found that its range would be perhaps five miles. This represents the distance from the station in which a practically interference-free signal can be obtained in a receiver. The frequency-modulation transmitter, on the other hand, would provide about a 20-mile day-and-night interference-free signal coverage.

With amplitude modulation if a radio receiver is tuned to a nearby standard broadcasting station, and the receiving antenna picks up even the faintest signals from a distant station operating on the same frequency, there will be a steady interfering note accompanying the wanted reception. If the strength of signals from the unwanted station is even $^1/_{100}$ the strength of the wanted signals, there will be interference. Thus, an amplitude-modulated transmitter 1,000 miles away may interfere with reception from a wanted station. The need for spacing amplitude-modulation stations on the same frequency so far apart is the major limiting factor in the total number that can be operated in this country.

Frequency-modulation stations do not set up such interference. Unwanted frequency-modulation signals must be at least one half the strength of the desired signal before interference results. Because such a high ratio of interfering power is required to disturb reception, frequency-modulation stations can be spaced geographically so that each frequency-modulation channel available can be used by a number of stations.

Frequency modulation is practically free from static and other interfering noises. It suppresses the annoying interference from distant stations. It provides a uniformly high standard service both night and day. These are all important factors from the viewpoint of community service. But, in addition, the frequency-modulation system of broadcasting provides for the transmission of the range of audible frequencies up to 15,000 cycles as compared with the 5,000-cycle range of our present amplitude-modulation system.

Figure 1. Four models of the General Electric "lighthouse" tube which is expected to play an important part in the postwar development of television, radio relaying, and other ultrahigh-frequency services

At the start of the war there were 43 commercial frequency-modulation stations and six experimental stations. Also, there were perhaps 500,000 frequency-modulation receivers. There are now 210 applications for frequency-modulation broadcast transmitters in the hands of the Federal Communications Commission. As a matter of general interest and as an augury of the future, it may be mentioned that there are also on file 77 applications for amplitude-modulated broadcast stations and 59 television stations.

It is expected that ultimately there will be well over 1,000 frequency-modulation transmitters in the United States. They not only will serve metropolitan and urban areas but also make possible new and additional service to small communities, which now have inadequate service or none at all. There are 606 cities in the United States, aside from the 96 metropolitan centers, having populations in excess of 10,000 and 579 of them do not have broadcasting stations. Although 331 are contiguous to the metropolitan centers, from which they obtain various degrees of programming service, many of them would benefit by the erection of local stations.

More than 15,000 cities or towns having populations of less than 10,000 are without local broadcasting facilities, and many of them undoubtedly would derive substantial benefit from the operation of local low-powered frequency-modulation stations. They would improve, and add significantly to, the ever-increasing service which standard broadcast stations have rendered to such areas.

The influence of low-power stations in the outlying and smaller communities is important. Such local broadcasting stations are destined to become an essential part of the American broadcasting system. They may be expected to have an important influence on business, social, religious

Figure 2. Exterior of the General Electric television and frequency-modulation transmitter station in the Helderberg Mountains near Schenectady and Albany, N. Y.

Figure 3. How television programs are relayed from New York to Schenectady for rebroadcast from station WRGB

educational, political, and agricultural activities. They will create new interest in local, social, and political matters, they will afford local entertainment talent an opportunity to develop, and they will broaden generally the outlook of people in smaller communities.

Frequency modulation also will permit expansion of the noncommercial broadcast services, which today are offered by approximately 40 stations. These stations are supported by universities, agricultural colleges, polytechnical schools, vocational institutions, Bible institutions, and churches. Part of the frequency-modulation radio spectrum (presently between 42 and 43 megacycles) has been set aside by the Federal Communications Commission for these noncommercial educational broadcasting services.

It can be seen readily, therefore, that many people who have wished to operate standard broadcasting stations and who were prevented in the past by the lack of space in the frequency spectrum will be in a position to obtain the necessary licenses. This fact is of importance to the listening public, to the radio manufacturing industry, and to broadcasters.

As the size of the national frequency-modulation audience increases, there should be sufficient frequency-modulation stations across the country to permit the organization of new national networks comprised of frequency-modulation stations. For all practical purposes, frequency modulation, with its present allocation in the radio spectrum, will provide as many broadcasting frequencies as there will be broadcasters to use them. However, the number of stations doubtlessly will be limited by economic considerations.

Probably the ultimate in mass-entertainment service is television. Perhaps for that reason, it is, at the moment, by far the most complex both technically and economically. As a sign of its technical complexity, it should be noted that the channel width for a 525-line television picture is six megacycles, as compared with a ten-kilocycle channel for amplitude-modulated sound broadcasting and 200 kilocycles for a frequency-modulated sound channel. In this six-megacycle channel must be placed the video signals plus the associated synchronizing impulses, together with the frequency-modulated sound signals.

Television is particularly complex in being one of the so-called lock-and-key services. The transmitter and receiver must be designed so that any receiver may receive the programs of any transmitter; for example, the synthesis of the picture which takes place on the face of the picture tube in a television receiver must be in synchronism with the analysis of the original scene as viewed by the camera tube in the television studio.

As the result of the work of the National Television Systems Committee, there was submitted to the Federal Communications Commission on March 20, 1941, a group of standards recommended by the radio industry. On July 1, 1941, the Federal Communications Commission approved these standards substantially as submitted and followed with the licensing of commercial television transmitters. However, before any great progress had been made, all work was discontinued because of the war.

At present nine television transmitters are operating in the United States. The number of television receivers in the hands of the public is approximately 10,000. The television industry is confronted with a number of problems, both technical and economic.

There is the question of whether or not a 525-line picture provides sufficient detail to hold the interest of the public. If greater detail be necessary, then the channel width must be increased, which in turn involves the use of the higher-frequency portions of the spectrum, perhaps about 400 megacycles.

The widening of this channel to provide for a picture of increased resolution suggests that the channel width should be further increased to perhaps 15 to 20 megacycles to permit color television.

Then there is the problem of interconnecting or chaining television transmitters. Certainly, if television is to become a national service, television transmitters must be connected for network operation.

Two lines of attack on this problem are evident, namely, radio relays and the use of coaxial cable. It is too early to deduce the probable solution, although there is a real possibility that both relays and cables may be utilized.

There is the further problem of the program material and how the cost of programs will be recovered. Naturally, all program-originating sources, such as the legitimate theater, the motion-picture industry, and the like are vitally interested and concerned with a service which may become a serious competitor. Whether television will become an ally or a competitor to such forms of entertainment remains to be seen.

From the experience with sound broadcasting, one might predict that the program cost will be recovered through advertising. While this is certainly a reasonable prediction, it is again perhaps too early to say that this will be the only source of revenue.

Television in the home is but one possible application. There are, in addition, such applications as the theater, display purposes in department stores, and industrial purposes. While some work has been done in these fields in both the United States and England, such applications have not proved their worth either technically or economically.

There is no doubt but that the technical advances due to the war will accrue to the advantage of television, although some time will be required to adapt these new tools and techniques to commercial application. In certain instances, such as the cathode-ray tube (picture tube), the benefits of better manufacturing processes will be available almost immediately.

Since the frequencies employed in both frequency modulation and television permit what is essentially line-of-sight propagation, a considerable number of transmitters will be required to provide a complete national coverage. Also, since for the same coverage the first cost of television transmitting equipment is, at the moment, appreciably greater than for sound broadcasting, it may be expected that the initial expansion will take place in the large urban centers. The fact that large urban centers are generally a good source of program material is also an important factor. Certainly, television will come after the war. We must, however, not expect it to blossom on nation-wide scale at once. A large investment must be made in television transmitters and in a system of connecting transmitters for network televising.

There is a third service, radio facsimile, which eventually may find application in the field of mass entertainment. Prewar attempts to commercialize this service for home use were not very successful.

During the war the applications of facsimile have been extended with a corresponding improvement in the equipment. Whether or not the technical advances will permit, economically, the

establishment of a service providing for a facsimile newspaper in the home must await lifting of military censorship of the technical information. In addition, there is the question of whether the public desires such a service and, if so, at what price.

Though we have considered only the mass-entertainment services, it is believed that we may expect confidently a comparable growth in all the electronics applications which were in existence prior to the war. There also will be a great many new applications as a result of the war developments. These applications will concern such services as aviation, marine, and, in general, all communication work, but also will make their imprint on industry for such purposes as rectification, inversion, heating, instrumentation, control, inspection, sorting, and precipitation.

Lighting a British Underground Factory

WINDOWLESS factories have been built which depend entirely on artificial illumination, but unusual problems were encountered in the lighting of an underground factory producing airplane-engine components in Great Britain, according to an article published recently in *Electrical Review*, London. Areas of unusual dimensions and restricted mounting heights required special consideration in the selection and spacing of fixtures. The accompanying illustrations show the installations used to obtain several levels of intensity; Figures 1 and 2, sections with high-intensity lighting, Figure 3, medium-intensity; Figure 4, low-intensity.

Figure 1 (left). Local lighting supplements general lighting from fluorescent fixtures in a bay 116 feet by 19 feet and provides 75–100 foot-candles for extra-fine inspection work

Figure 2 (above). Eighty-watt fluorescent lamps at a mounting height of seven feet provide 25 foot-candles at drawing-board level in an office

Figure 3 (left, below). A machine-tool section in a 16-foot-high corridor, 600 feet by 16 feet, is served by two lines o 80-watt fluorescent reflectors, with 40 in one line and 41 in the other; additional local lighting is provided at the machines

Figure 4 (below). A small corridor requiring only three to five foot-candles is lighted by 40-watt incandescent lamps

INSTITUTE ACTIVITIES

Papers Now Available for Discussion on AIEE Wartime Program

Nineteen technical papers now are available for discussion by mail as the Institute places in effect plans that have been devised to continue the preparation, discussion, and publication of papers while complying with wartime restrictions on meetings (*EE, Mar. '45, p 110*).

Abstracts of the papers that are available by mail in pamphlet form are given in the section immediately following. Pamphlets may be ordered at the prices shown from the AIEE Order Department, 33 West 39th Street, New York 18, N. Y. Coupon books in five-dollar denominations are available for those who may wish this convenient form of remittance. A convenient order form is included in an announcement of the AIEE technical-program committee's "spring technical-paper program" that is being mailed to all AIEE members.

Discussion of the papers is invited and should be mailed in triplicate before the closing date of May 15, 1945, to C. S. Rich, secretary of the technical-program committee, AIEE headquarters, 33 West 39th Street, New York 18, N. Y. The papers and approved discussion ultimately will be published in AIEE *Transactions;* many of the papers, as determined by budget and paper limitations, will appear in *Electrical Engineering*.

ABSTRACTS • • • •

Air Transportation

45-85—Governor Requirements for Aircraft-Alternator Drives; *W. K. Boice* (*M '43*), *L. G. Lavoy, Jr.* (*M '43*). *25 cents.* The development of a-c electric systems for aircraft has given rise to a need for variable-ratio transmissions which can receive mechanical power from main aircraft engines and deliver it at substantially constant speed to a-c generators in spite of wide variations of engine speed. Governors for such drives require sufficient response to maintain generator speeds within close limits even during periods of engine acceleration and deceleration. Parallel operation of alternators has a pronounced influence on governor requirements. This paper presents the results of an analytical treatment of the problem of determining the governor response required during periods of engine acceleration. A method is described for calculating performance under a variety of conditions. Examples have been worked out which illustrate the nature of the phenomena involved and help to evaluate the relative importance of several design features and operating characteristics of transmissions and governors.

45-86—Selenium Power Rectifiers for A-C Aircraft Systems; *A. L. Embry* (*A '40*). *15 cents.* To furnish the electric power required by modern large aircraft, a-c electric systems have been developed. Work has been done on two systems: one operating at constant frequency and the other with frequency varying as the main-engine speed. As considerable amounts of d-c power still are required in most cases, selenium rectifiers have been developed to supply this power from the a-c lines. In this paper are described three-phase rectifiers designed to provide regulated d-c power at 28.5 volts, using saturable core reactors and standard aircraft-type voltage regulators to control the output voltage. Rectifier units for both constant and variable-frequency systems are discussed, with current rating of 100 to 800 amperes.

45-87—400-Cycle Aircraft Motor; *G. O. Schwandt* (*A '39*). *20 cents.* The ever-present need for lighter-weight and more compact aircraft electric motors is evident, since any reduction in weight or space provides increased fuel, bomb, or pay-load capacity. Reliable 400-cycle motors, more compact and lighter than existing 24-volt d-c motors, have been developed recently. Some of these motors are described in this paper. Also, the motor requirements and characteristics are discussed.

45-96—A 208–120-Volt 120-Ampere 400-Cycle Electrically Operated Aircraft Circuit Breaker; *C. H. Titus* (*A '40*), *P. J. Reifschneider* (*A '43*). *15 cents.* With the selection of the 208–120-volt three-phase 400-cycle a-c system by the Army Air Forces for large aircraft, there has arisen the need for appropriate switchgear. In order to be applicable to the systems of such airplanes, switchgear must be able to perform its normal and emergency functions under the encountered conditions of temperature, pressure, humidity, vibration, and acceleration. This paper describes a 120-ampere remotely controlled electrically operated air circuit breaker designed for use as a bus-sectionalizing ring-tie or generator breaker on the 400-cycle grounded-neutral system. The interrupting rating of this breaker is 3,800 amperes at all pressures from sea level to 50,000 feet altitude. The closing solenoid and shunt trip have been designed to operate over a wide range of ambient temperature and control voltage. Being primary considerations in aircraft equipment, the weight and size of this breaker have been held to a minimum.

45-88—A Current-Limiting Fuse for Aircraft Applications; *A. H. Powell* (*A '43*). *15 cents.* The capacity of aircraft electric systems has increased to a point where available fuses may not be satisfactory for the duty imposed on them. Furthermore, higher voltages are being used in order to transmit more power without using larger cables. A fuse is an ideal short-circuit protecting device, but it must be built properly and correctly applied. To meet the present and anticipated future requirements, a new current-limiting fuse has been designed for aircraft applications. This fuse, based on the well-known and time-tested design of high-voltage power fuses, has been built particularly for 208–120-volt three-phase 400-cycle applications and has an interrupting rating of more than 4,000 amperes. Tests have shown it is equally well suited for 120-volt d-c circuits requiring similar high interrupting capacities. The new fuse has been designed with the principal requirements of light weight, reliability, and reasonable life as major factors. Several departures from customary fuse designs have been necessary to accomplish the desired results. Steps followed in developing the new fuse and tests made in evolving and checking the new design are described along with a brief résumé of factors to be considered in applying and operating the fuse for most satisfactory results.

Electric Machinery

45-92—Per-Unit Impedances of Synchronous Machines; *A. W. Rankin* (*A '38*). *20 cents.* This paper shows that rated stator kilovolt-amperes and voltage are not sufficient to determine all the per-unit impedances of a synchronous machine. It shows that the only impedances which can be given in terms of rated stator kilovolt-amperes and voltage are those which are measurable from the stator terminals and that all the internal machine impedances require the specification of some quantity in addition to the stator kilovolt-amperes and voltage before their per-unit value can be determined. Generalized per-unit formulas are developed, in which this additional quantity is given in terms of the selected rotor-circuit base currents. The use of these formulas will result in a consistent and consonant system of per-unit impedances.

45-93—A Generalized Circle Diagram for a Four-Terminal Network and Its Application to the Capacitor Single-Phase Motor; *J. G. Tarboux* (*F '43*). *30 cents.* The main purpose of this paper is to present an operating circle diagram for the capacitor motor, showing that the input-current vector follows a circular envelope as the mechanical shaft power is varied. A secondary aim is to review the theory of the generalized four-terminal network, thereby developing circle-diagram equations which can be applied to any linear network which delivers its output power into a variable impedance of constant power factor. This generalized method of approach can be applied quite readily to the three-phase induction motor and the same results can be obtained, which are now available in practically all textbooks on

a-c machinery. The same point of view can be extended to single-phase motors, the capacitor motor being a good example. Considerable work still remains to be done in order to make the single-phase circle diagram as useful as the one commonly used for three-phase motors, but the author feels that the generalized treatment offered in this paper may be a step in the right direction.

45-94—Winding-Fault Detection and Location by Surge-Comparison Testing; *G. L. Moses* (*M '44*), *E. F. Harter* (*A '42*). *15 cents.* Surge-comparison methods of testing insulation were investigated with the objective of locating as well as detecting faults. Experience of other investigators was confirmed, and limitations of methods and equipment were studied. Supplementary methods and equipment were devised to extend the field of usefulness of this basic type of tester, especially to the testing of very large machines with multiple-parallel windings. Apparatus studied included a-c motors from fractional-horsepower single-phase to very large three-phase types; a large variety of d-c armatures; and numerous armature, stator, and magnet coils. This surge-comparison tester has proved to be suitable for use by electrical manufacturers and by service and repair shops, as it can be used for testing most common types of electric windings.

45-95—Control of Electrical Insulating Varnishes; *D. L. Gibson* (*A '44*), *C. H. Braithwaite* (*A '45*). *15 cents.* The quality of the varnish film deposited depends upon the condition of the varnish in the processing tanks. Thickness of deposited-varnish films varies with viscosity and body. Heavy films interfere with coil sizes and increase problems of heat transfer. Thin films give inadequate protection. Conducting contaminating materials constantly are introduced into the tanks. These indicate close control of tank varnish is necessary for consistently high quality of apparatus treated. Methods of control are discussed, which include laboratory tests, physical tests, and a daily inspection of tanks. Portable cold-pressure filtering for removing much of the contamination present is described. Insulating varnishes are complex chemical mixtures, and care should be maintained in their use. It is important that they be under the control and supervision of persons with the proper training and experience. Constant quality control is necessary for satisfactory results.

45-97—Chemical Contamination as a Cause of Electrical-Insulation Failures; *C. H. Braithwaite, Jr.* (*A '45*), *G. L. Moses* (*M '44*). *15 cents.* Electrical-insulation failures were investigated and found to be caused by chemical contamination with ionizable materials. Examples of such contamination are certain types of hand creams, soldering fluxes, and germicides in lubricating oils. Contamination mechanisms often involve operations which are otherwise insignificant in manufacturing processes. The effect of these materials is reported on the electrical characteristics of the insulation. The need for close correlation of industrial hygiene, manufacturing processes, insulation design, and quality control is emphasized.

Instruments and Measurements

45-90—Basic Concepts of Moving-Magnet Instrument Rotors; *L. I. Mendelsohn* (*A '41*). *25 cents.* The performance of permanent-magnet instrument rotors is rationalized on the basis of electromagnetic theory. Procedures are given for predicting this performance and for selecting the material best adapted to the operating conditions. By analysis of the magnetic behavior of rotors of elliptic-spheroid shape immersed in a uniform field, their intrinsic induction, their magnetic moment, and the mechanical torque which they will produce are determined. The elliptic-spheroid shape serves as a good approximation of most practical instrument rotor designs.

45-100—Precision Testing of Electric Tachometers; *M. A. Princi* (*M '45*). *15 cents.* The magnetic-drag electric tachometer which was developed especially for the measurement of aircraft-engine speed is inherently a more precise measuring device than those instruments which normally have been used as reference standards of speed measurement. This paper describes an electric-tachometer testing system which meets the requirements of high accuracy and is also suitable for large-quantity manufacture of tachometers. The system provides facilities for testing at 22 scale points in a range of speeds from 500 to 4,500 indicated rpm without referring to a standard instrument. The power to drive the tachometers being tested is supplied from tachometer generators, which are driven by a d-c motor controlled by a precision tuning fork. The method of operation and the control system are explained.

45-101—Analysis and Design of a D-C Selsyn System; *Joseph Manildi. 20 cents.* In this paper the author presents a rigorous analysis of a conventional d-c Selsyn remote-indicating system. The first part of the analysis shows that a natural error exists in the system, which has a 60-degree cycle and which reaches a maximum value of 1.1 degrees. The error is zero at each 30-degree point and reaches a maximum almost midway between the 30-degree points. The natural error of the Selsyn system arises from the fact that the transmitter resistance is a linear function of the transmitter angle θ. This natural error may be overcome by designing a transmitter resistance in a nonlinear manner. The equation is developed for the necessary variation of the transmitter resistance with the transmitter angle. Furthermore, the shape of the toroid on which this resistor should be wound to give this desired variation is derived therefrom. The paper further presents optimum values of resistances for both transmitter and receiver, in order that the greatest amount of torque may be transmitted to the receiver for a given amount of power.

Land Transportation

45-83—Measurement of Railway-Motor Temperatures in Service; *J. W. Teker* (*A '37*). *20 cents.* The question of operating temperatures of Diesel-electric-locomotive electric equipment is of more than academic interest; it is an active factor exerting its influence with time on the life of the equipment and is worthy of economic consideration. The application of motive power to a given duty can be made correctly only with full knowledge of resulting apparatus temperatures. Application studies may be difficult at times, when variables of uncertain magnitudes are encountered. However, temperatures can be measured in actual service accurately and quickly by using the recognized resistance method properly adapted to the conditions encountered in railway operation. The technique and equipment developed to meet these conditions and perfected by experience in actual practice provide a means of obtaining temperature data, valuable to railroad operating and motive power departments, as well as for the application and design engineer.

45-84—Dynamic Braking With Traction Motors; *L. G. Riley, G. M. Woods* (*M '43*). *15 cents.* Retardation with traction motors, either independently or as an adjunct to mechanical braking, has been utilized in various forms on practically all types of electric vehicles from battery trucks to main-line locomotives. In some cases, it is used only to maintain uniform speeds on long grades and in others to make regular service stops. While the general principles are nearly as old as the electric-traction industry itself, in recent years numerous refinement have greatly extended the usefulness of dynamic braking by affording improved performance, additional safety, and simplification of mechanical braking systems. This paper discusses the various means by which favorable results have been accomplished, with a minimum amount of additional electric equipment.

45-91—Rewinding Commutator-Type Traction Armatures; *N. J. Greene* (*M '45*), *D. E. Stafford* (*A '37*), *C. Gentilini* (*A '32*). *25 cents.* With the increased number of electric locomotives in use, the longer hours of operation, and the heavier loads, old maintenance problems have been accentuated; new ones have arisen. The object of this paper is to review for those experienced in the art of armature rewinding and to cite for the newcomer some of the important and frequently overlooked factors which must be considered in restoring a damaged armature to its original condition and in modernizing and improving consistently with current practices. The factors are discussed under the following headings:

1. Analysis of failure.
2. Cleaning.
3. Magnetic inspection.
4. Commutator.
5. Rewinding materials.
6. Armature windings.
7. Banding.
8. Impregnating.
9. Balancing.

Railway armatures present an interesting though difficult problem, since they must withstand the severe strains imposed upon them by varying loads at varying speeds, plus the several combinations of vibration and strains resulting from train motion and roadbed shock, often with rapidly changing ambient temperatures.

Akron Section inspects the new Gorge power plant of the Ohio Edison Company, Akron Ohio, on the occasion of the Section's first meeting of the 1944–45 season

Quality Control

45-89—Statistical Methods Applied to Insulator Development and Manufacture; *AIEE subcommittee on application of statistical methods. 75 cents.* This paper has been written for engineers who are, like the author, amateurs in the application of statistical methods. It illustrates by examples taken from the field of high-voltage-insulator manufacturing, certain types of problems that benefit by statistical treatment. Only a passing reference is made to quality control of product, since studies of this subject are readily available. Particular attention is called to significant patterns in the distribution of test observations and to physical causes that nonnormal patterns may imply. Since in destructive testing two distinct tests cannot be made on a single specimen, statistical analysis is almost indispensable for the correlation of product characteristics. As an example of such an inquiry, the relationship between short-time and time-load tests is explored by statistical methods. Other sections of the paper discuss the relationship between quality control and routine testing of product, and the limitations of sampling as a means of determining product characteristics.

45-99—Statistical Tools for Controlling Quality; *Joseph Manuele (M '44), Casper Coffman. 20 cents.* The application of mathematical statistics for controlling the quality of products gives the manufacturer three tools:

1. The frequency distribution enables him to determine, very soon after production has started, what the quality of the product is likely to be.

2. The control chart enables him to detect variations in statistical control, so that he can take corrective measures to avoid producing products which will fall outside of specification limits.

3. Analysis of variance enables him to check for significant differences between parts produced by different tools.

45-98—Application of Quality Control to Resistance Welding; *L. S. Hobson (M '39), R. S. Inglis, R. P. McCants. 75 cents.* Quality control has been applied successfully to resistance welding in the fabrication of electric switchgear. The methods of testing and control have been in use for over two years and give assurance of uniform weld quality. Standardization of the process is essential to its control. Standard tables covering machine settings for all combinations of materials normally used in switchgear structures make possible uniform welding practice in the shops. Welded specimens are prepared each hour under the same conditions of production welding. These specimens are tested in torsion in special testing machines to determine ultimate torque, angle of twist, and weld diameter. These factors are combined to give a quality number or index. Averages are plotted on a control chart posted on each machine. Weekly reports are issued showing the performance of each machine and the over-all control of the process. Resistance welding, properly controlled, becomes a safe dependable fabrication process.

AIEE Executive Committee Meets at Headquarters

A transfer of Section territory, approval of recommendations of the Standards committee, and confirmation of proposed joint activity for the AIEE were among the matters considered at the meeting of the executive committee held February 27, 1945, at Institute headquarters.

Upon recommendation of the Standards committee a revision, prepared by the committee on automatic stations, of "American Standard for Automatic Stations, *C*37.2" AIEE Standard 26 was approved, for submission to the American Standards Association. The following were adopted for publication: Final revision, prepared by a subcommittee of the committee on electric machinery, of the "Test Code for Synchronous Machines," which has been available in pamphlet form as a report since January 1937; final revision, by the committee on protective devices, of the report on "Standards for Fuses Above 600 Volts," which has been available in pamphlet form as a report since July 1941; report of the Joint AIEE–ASME Committee on Turbogenerators on "Proposed Preferred Standards for Large 3,600-Rpm Three-Phase 60-Cycle Condensing-Type Turbogenerators."

An appropriation was made for a second printing of the report on "Electric Power Distribution for Industrial Plants" as the small number of copies remaining in stock is insufficient to meet the demand.

Upon approval of the Sections concerned and the vice-presidents of Districts 5 and 2, and upon recommendation of the Sections committee, it was voted to transfer Auglaize County, Ohio, from the Fort Wayne Section in District 5 to the Dayton Section in District 2.

AIEE subscription to the Canadian Radio Technical Planning Board was authorized, as recommended by W. J. Gilson (M '38) vice-president of the Canada District. (The Institute became a contributing sponsor of the Radio Technical Planning Board in the United States in October 1943.)

Pursuant to the action of the board of directors in January in referring the matter to the executive committee for action, it was voted that the Pacific Coast technical meeting scheduled to be held in Seattle, Wash., in August 1945 be postponed to 1946.

The technical-program committee and the committee on electronics were authorized to take such part as may be desirable in the electronics conference scheduled to be held in Chicago, Ill., on a local basis in 1945, of which the Chicago Section of the AIEE will be a sponsor.

F. A. Cowan (M '29) chairman of the technical-program committee, reported on plans of the committee for continuing the technical-program activities of the Institute during the cessation of meetings (see page 156 of this issue). The plans were approved.

In view of the cancellation of the 1945 summer technical meeting, during which the annual business meeting of the Institute would have been held and the board of directors' action in January in referring to the executive committee decision on time and place of the annual meeting, a resolution was adopted that the 1945 annual business meeting be held at AIEE headquarters New York, N. Y., on Wednesday, June 27.

To fill the unexpired terms of the late H. L. Huber, J. J. Pilliod (F '34) was appointed an alternate representative of the Institute on the Standards Council of the American Standards Association for the unexpired term, ending December 31, 1945, and a representative on the electrical standards

committee of ASA to fill the unexpired term, ending July 31, 1945.

Three members of the Institute were designated to represent the AIEE at the annual meeting of the American Academy of Political and Social Science in Philadelphia, Pa., April 13–14, 1945, namely: C. H. Black (A '41), N. E. Funk (F '34), and I. M. Stein (F '39), all of Philadelphia.

Present at the executive committee meeting were:

C. A. Powel, chairman; P. L. Alger, J. F. Fairman, W. R. Smith; H. H. Henline, national secretary; F. A. Cowan, chairman of the technical-program committee (during discussion of plans of that committee).

Recommendations adopted by the board of examiners at a meeting held February 15, 1945, were reported and approved. Upon recommendation of the examiners, the following actions were taken: seven applicants were transferred to the grade of Fellow; 34 applicants were transferred and 38 were elected to the grade of Member; 189 applicants were elected to the grade of Associate, and one Associate was reinstated; 177 Student members were enrolled.

Subcommittee on Statistical Methods Announces Year's Program

Preparation of a series of short articles on statistical methods which will appear in *Electrical Engineering* beginning next month is part of the program for the year announced by the subcommittee on statistical methods of the AIEE Standards committee. The subcommittee, appointed in October 1944, held a conference during the recent AIEE winter technical meeting (*EE Mar '45, pp 177–78*).

The activities announced by the subcommittee are as follows:

1. An educational program including

(*a*). A series of short technical articles developing the subject from first principles.

(*b*). Articles describing special applications of statistical methods.

(*c*). The sponsoring of the presentation of papers at Section meetings; also the sponsoring of technical conferences and sessions at District and national meetings when these are resumed.

(*d*). General articles addressed primarily to executives, pointing out the advantages of statistical methods.

2. A study of applications in Institute test codes and Standards.

3. Applications in the electrical utilities' field.

4. Co-operation with Doctor Shewhart's Joint Committee on Applications of Statistical Methods in Engineering and Manufacturing.

5. Keeping in touch with developments in which the Institute might properly co-operate.

The work of the subcommittee is described by W. P. Dobson, chairman, as follows:

While statistical methods have been applied in industry for many years, their use has been extended widely since the beginning of the war. The necessity of providing war materials in vast quantities under exacting tolerance requirements naturally directed attention to quality control of items produced by mass-production methods. The methods developed in the Bell Telephone Laboratories through the pioneer work of Walter A. Shewhart have found extensive applications in American and British industries and have aided the war effort tremendously by effecting improvement in quality, increased production, and reduction in costs.

The Office of Production Research and Development and the United States Office of Education have added impetus to the interest thus aroused by organizing in co-operation with universities intensive courses of training in statistical quality control. The National Research Council has set up committees covering the whole field; one of these, under the chairmanship of Doctor Shewhart is the Joint Committee for the Development of Statistical Applications in Engineering and Manufacturing. In October 1944 AIEE accepted an invitation from Doctor Shewhart to participate in the work of his committee.

In view of the widespread interest in the subject and of the fact that the Institute had not given much attention to it previously, the Standards committee at its meeting in October 1944 appointed a subcommittee to explore the possible applications in the Institute's field and to ascertain the reaction of the membership. As a first step a conference was held at the winter meeting in January. The large attendance and comprehensive discussion of the conference papers provided convincing evidence of a keen interest among the Institute membership and was of great assistance to the subcommittee in preparing its plans for the coming year.

EDUCATION PROGRAM

The primary obligation of the subcommittee appeared to be the dissemination of information about statistical methods as widely as possible among the membership of the Institute, including the essential theory and the technique of application. Most of the articles which have appeared in the Institute's publications have presupposed a knowledge on the part of the reader which is possessed only by experts, and have been criticized on the ground that they were difficult to read because of the unfamiliar technical terms used and lack of detailed explanation of the various steps in the reasoning. Most electrical engineers have not received instruction in the theory of probability and its applications, and, while excellent textbooks are available and the literature of the subject is extensive, it may appear to the interested engineer a formidable task to acquire the necessary knowledge in order that he may apply the methods in his work. This is not the case; it is not necessary to have a thorough understanding of statistical theory or a knowledge of advanced mathematics in order to apply the control techniques.

An adequate foundation may be laid without mastering the contents of a voluminous textbook.

It therefore appears appropriate to give the Institute membership the opportunity of acquiring the necessary fundamental knowledge without an undue expenditure of time. A small group of experts has been appointed to prepare a series of papers for publication in *Electrical Engineering*. These articles will develop the subject from first principles and will lay a foundation for further study and for an understanding of specialized articles of an advanced character. They will be short and will form a series beginning in the May issue. Carefully prepared bibliographies will be included to guide readers who may desire to make a more extensive study. The subcommittee invites those having special experience to submit articles on special applications.

CONFERENCES AND SESSIONS

The maximum benefit in the development of any subject results from discussion. The subcommittee therefore proposes to the Sections that they consider the inclusion of papers in their programs for the coming year and offers its assistance in suggesting subjects and speakers.

INSTITUTE TEST CODES AND STANDARDS

The principal term of reference in the instructions to the subcommittee was the application of statistical methods in Institute test codes and Standards. The educational program is a stepping stone to this final goal. It is designed to lay a foundation of knowledge and to arouse an interest in the membership generally and in the technical committees, so that the way may be prepared for co-operation between them and the subcommittee in the study of these applications. Progress will depend upon careful study and close analysis of all factors. As a beginning it has been suggested that the aircraft field, one of the most recent activities undertaken by the Institute, may provide a subject, and aircraft generators and motors have been chosen. A group has been formed containing representatives from the subcommittee for aircraft electric rotating machinery and the subcommittee on statistical methods to study this question.

APPLICATIONS IN UTILITIES FIELD

Although at the present time quality control in production is of paramount interest, statistical applications in inspection by purchasers are important. Reduction in inspection costs with maintenance of quality are of importance to the utilities who are large purchasers. Sampling by the purchaser is a fundamental factor and should be correlated with production control methods. This will be given attention. Other applications in the utilities' field will be given attention as the opportunity arises.

GENERAL

Doctor Shewhart's committee will provide a forum wherein the Institute may join with other national societies and assist in securing the maximum co-operation and the ideal correlation of their various activities.

CONCLUSION

The program sketched herein is an ambitious one, and it is obviously impossible under present conditions to carry forward all the projected activities in the immediate future. The most pressing war needs demand first attention, but the impetus given to the subject by the war without doubt will result in a continued expansion of statistical applications in the postwar period. The Institute has a vital interest in giving leadership to its members and assistance to industry and the public, to the end that all elements of the electrical industry and of the profession may play their part most efficiently.

The personnel of the subcommittee of the Standards committee is as follows:

M. M. Brandon, Underwriters Laboratories, New York, N. Y.

H. F. Dodge, Bell Telephone Laboratories, New York, N. Y.

C. M. Gilt, Consolidated Edison Company of New York, New York, N. Y.

L. S. Hobson, General Electric Company, Philadelphia, Pa.

J. Manuele, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

A. I. Peterson, Radio Corporation of America, Camden, N. J.

W. P. Dobson, Hydro-Electric Power Commission of Ontario, Toronto, Canada (chairman).

SECTION

Engineers in Sacramento Form AIEE Subsection

With a nucleus of only eight Institute members resident in the area, a Sacramento (Calif.) Subsection of the San Francisco Section has been organized following four trial meetings initiated last November. Officers have been elected with W. E. Camp (M '22), consulting engineer, as chairman and E. A. McGinty, Pacific Gas and Electric Company, as secretary–treasurer, and a regular series of monthly meetings has been programmed.

It was decided to attempt organization of a Subsection when it was realized that a large number of engineers in the region might be interested in joining the Institute, provided local meetings could be held. As a result, a Subsection committee under the chairmanship of W. A. Lindblad was appointed with membership drawn from members and nonmembers in Sacramento. The local committee set up a mailing list of approximately 150 engineers and, in addition, had posters placed on bulletin boards in plants and offices announcing the first meeting which subsequently boasted an attendance of 172, including a representative group from San Francisco.

The Sacramento Subsection is operated through funds provided by the San Francisco Section. Its program for the coming year will offer speakers drawn from Section membership, and an endeavor is being made to secure the services of visiting speakers also.

PERSONAL

F. A. Lewis

W. R. MacDonald, Jr.

F. A. Lewis (A '31, M '35) acting editor of AIEE publications since 1942, has resigned to become vice-president of the Hooton Chocolate Company, Newark, N. J. Born in Carverton, Luzerne County, Pa., January 20, 1903, Mr. Lewis was graduated from Syracuse University in 1926 with the degree of electrical engineer. At once he became associated with the Consolidated Edison Company of New York (N. Y.), Inc., and from 1926 to 1929 served in the test department. In 1929 he was transferred to the transmission and distribution department. During 1930 and 1931 he was engaged in magnetic research work as a member of the technical staff of Bell Telephone Laboratories, Inc., New York. From 1928 to 1931 he taught industrial mathematics in the evening school of Pratt Institute, Brooklyn, N. Y. Mr. Lewis joined the AIEE editorial staff in 1931 as assistant editor, and in 1936 he became associate editor. He is a member of Tau Beta Pi and Pi Mu Epsilon, and is currently serving as a member of the executive committee of the New York Business Paper Editors.

W. R. MacDonald, Jr. (A '33, M '44) AIEE assistant editor, has been appointed acting editor. He was born August 22, 1910, in New York, N. Y., and received the degree of electrical engineer from Cornell University in 1932. After his graduation he established and operated a radio service and repair business until in 1934 he joined the AIEE editorial staff. In 1938 he was named an assistant editor. Mr. MacDonald, who had been commissioned a second lieutenant in the Signal Corps Reserve of the United States Army in 1932, was called to active duty as a first lieutenant in 1941. He was assigned to the Office of the Chief Signal Officer in Washington, D. C., as head of the literature subsection, military training branch, and in this position he was responsible for the preparation of field and technical manuals for the Signal Corps. He was successively promoted to the ranks of captain and major. In 1944 he was released from active duty, and he returned to the Institute's editorial staff. Mr. MacDonald originally was employed by AIEE during the period of a major change in publication policy and while the May 1934 50th anniversary issue of *Electrical Engineering* was under preparation. His many contributions have been of material assistance in the subsequent maintenance and development of the Institute's publication services. He is a member of Eta Kappa Nu and a fellow of the Radio Club of America.

N. B. Hinson (A '19, F '35) formerly chief engineer, Southern California Edison Company, Ltd., Los Angeles, has been elected vice-president and executive engineer of the company. Mr. Hinson joined the company then known as the Edison Electric Company, as testman in 1906. He was transferred to the distribution department in 1912 and named distribution engineer in 1913 and assistant superintendent of distribution in 1920. He became system planning engineer in 1923, assistant manager of operation in 1928, and chief engineer in 1934. **H. W. Tice** (A '34) formerly manager of operation, for the Edison Company also has been elected a vice-president of the company and will continue to direct operation. A graduate of Lehigh University, Mr. Tice, who became associated with the Edison Company in 1922, previously had been employed in steel manufacturing in Pennsylvania, South America, and Cuba. He was made operating engineer in 1927, assistant manager of operation in 1937, and manager in 1941. **W. E. Row** (A '39) formerly assistant manager of operation, succeeds Mr. Tice. He was first employed by the company from 1908 to 1915 at construction and distribution engineering work. After employment in Shanghai, China, from 1915 to 1921 as a manager of engineering for the Fobes Company, Ltd., he returned to the United States and after brief employment with the California Railroad Commission entered the distribution department of the Edison Company, becoming distribution engineer in 1927. He was made assistant superintendent of distribution in 1936 and assistant manager of operation in 1942.

W. L. Chadwick (M '38) formerly chief civil engineer of the operating department, has been appointed manager of the engineering department. A graduate of the University of Redlands, Mr. Chadwick joined the Southern California Company in 1928 as transmission engineer. From 1931 to 1937 he was employed as engineer and senior engineer on construction of the Colorado River aqueduct for the Metropolitan Water District of Southern California. Returning to the Edison Company in 1937, he was given charge of civil engineering. **W. N. Johnson** (A '22, M '30) formerly superintendent of distribution, replaces Mr. Row as assistant manager of operation. Mr. Johnson was connected with the Bureau of Power and Light of the City of Los Angeles before joining the Edison Company about 1932. A former manager of the company's Vernon City district, he has been superintendent of distribution since 1941. **L. F. Hunt** (A '21, F '38) formerly senior engineer in the operations department, has been appointed chief electrical engineer. Mr. Hunt, who holds the degrees of bachelor of science (1919) and electrical engineer (1929) from the University of Southern California commenced his career with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., for which he designed many types of protective relays from 1919 to 1922. He became assistant to the protection engineer of the Edison Company in 1922, development engineer in 1924, and protection engineer in 1930. In 1941 he was named senior engineer. He is the author of numerous technical articles and holds a number of patents for protective devices.

J. D. Enefer (A '43) engineer, has been made assistant to the manager of the engineering department. Mr. Enefer has been with the company since 1917 as operator, substation chief, division superintendent, and engineer.

C. T. Malloy (A '35) formerly superintendent of transmission and communication, has been named general superintendent of those departments. Mr. Malloy entered the company employ as a clerk in 1922 and later became patrol supervisor and assistant super-

intendent of transmission. **R. N. Coe** (A '42) formerly superintendent of underground, has been appointed assistant superintendent of distribution. He has been with the Edison Company since 1938.

T. F. Barton (A '12, F '30) of New York, N. Y., **W. O. Batchelder** (A '08) of Chicago, Ill., **L. T. Blaisdell** (A '20, F '39) of Cleveland, Ohio, **W. B. Clayton** (M '40) of Dallas, Tex., **E. H. Ginn** (A '03) of Atlanta, Ga., **A. L. Jones** (A '07, F '38) of Denver, Colo., **T. S. Knight** (A '05) of Boston, Mass., and **A. S. Moody** (A '09) of Portland, Oreg., all commercial vice-presidents, General Electric Company, Schenectady, N. Y., have relinquished their responsibilities for apparatus sales in their respective districts to become members of the president's staff for the purpose of furthering better customer relations. **C. W. Fick** (A '16, F '39) formerly district engineer, Cleveland, has been made district manager of apparatus sales for the company's East Central district. Mr. Fick joined the General Electric Company soon after his graduation from the University of Illinois in 1912. He was stationed in Schenectady and in Portland, Oreg. before his transfer to Cleveland. **R. I. Parker** (A '14, M '20) district manager, Chicago, has been made manager of apparatus sales for the district. Mr. Parker entered the employ of the company in Schenectady in 1912, the year of his graduation from the University of Kansas, and in 1913 was transferred to Chicago. **H. A. White** (A '40) district manager of the industrial department, Dallas, has been made district manager of apparatus sales. Mr. White has been with the General Electric Company since his graduation from the University of California in 1915 and has had his headquarters in Dallas since 1917.

F. H. Doremus (A '24, M '32) manager of the industrial department in Denver, has been made manager of apparatus sales for that district. Mr. Doremus, who was graduated from the University of Nebraska in 1922, joined the General Electric Company in Schenectady and in 1925 was sent to Denver. **A. G. Jones** (A '07) district manager of the central station transportation department, San Francisco, Calif., has been made manager of apparatus sales. A 1904 graduate of Alabama Polytechnic Institute, Mr. Jones has been with the General Electric Company since 1905 and in San Francisco since 1908. **H. E. Dunham** (A '09, M '39) formerly assistant manager, patent department, Schenectady, has been appointed manager. Mr. Dunham was graduated from Syracuse University in 1906 and received his law degree from George Washington University in 1913. He joined the General Electric Company in 1912 and has been assistant manager of the patent department since 1930. **H. M. Sliter** (M '43) formerly assistant district manager of the central station division, New York, has been appointed district manager of the division. Mr. Sliter was graduated from Cornell University and entered the test department in 1908. In 1927 he was transferred to the New York district office. **R. M. Darrin** (A '28, M '34) formerly manager of the company's Syracuse, N. Y., office, succeeds Mr. Sliter. A graduate of Amherst College, Mr. Darrin has been in the company employ since 1919 and has managed the Syracuse office since 1940.

J. R. Read (A '04) chairman and president, Canadian Westinghouse Company, Ltd., Hamilton, Ontario, has been elected to the board of directors of the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa. Mr. Read who has been president of the Canadian Company since 1939 and chairman since 1944, entered the employ of the Canadian Westinghouse Company in 1904 and before that had been employed by the Westinghouse company in Pittsburgh. **J. T. Mathews** (A '35) formerly engineering representative, Westinghouse International Company, Buenos Aires, Argentina, has been appointed assistant manager of the foreign engineering department, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa. Mr. Mathews, a 1927 graduate of the University of British Columbia, joined the Westinghouse organization in 1927 and the foreign engineering department in 1934. His work for the department has taken him to France, Germany, and England as well as Argentina.

C. R. Reid (A '08, F '44) superintendent of the Shawinigan Water and Power Company, Montreal, Quebec, Canada, has retired. Mr. Reid received the degrees of bachelor of science in 1906, and master of electrical engineering in 1912 from the University of Oregon and the degree of master of mechanical engineering from Cornell University in 1916. He had been employed by the Shawinigan Company since 1916 as electrical engineer, power house superintendent, assistant general superintendent, and after 1937 as general superintendent. Mr. Reid plans to open a private business in California. **W. R. Way** (M '42) formerly assistant general superintendent of the company, succeeds Mr. Reid. A 1918 graduate of McGill University, Mr. Way entered the employ of the company that same year as general engineering assistant. He was appointed chief system operator in 1924, superintendent of operation in 1935, and assistant general superintendent in 1940. **J. M. Sharpe** (A '27, M '44) formerly system operating engineer, has been appointed superintendent of the system operating division of the company. Mr. Sharpe was graduated from McGill University in 1925 and immediately afterwards joined the Shawinigan Company. **E. W. Knapp** (A '31, M '44) formerly acting head of the engineering division, has been appointed superintendent of the engineering division. Mr. Knapp, who is a 1923 graduate of McGill University, entered the employ of the Shawinigan Company in 1925. **A. L. Hough** (M '43) formerly assistant superintendent of distribution stations, has been appointed superintendent of substations division. Mr. Hough was employed by the Shawinigan Company from 1922 to 1928 and, after his graduation from McGill University in 1933 returned to its employ.

L. G. Dandeno (A '18, M '44) formerly superintendent of the Thunder Bay system of the Hydro-Electric Power Commission of Ontario, Cameron Falls, Canada, has been appointed superintendent of the Eastern Ontario division of the Southern Ontario system. Mr. Dandeno joined the Ontario Commission after his graduation from the University of Toronto in 1916 and has been superintendent of Thunder Bay since 1923. **J. W. Looney** (A '32) superintendent for the Commission at Fitzroy Harbour, will succeed Mr. Dandeno. Mr. Looney has been with the Commission since 1930, the year he graduated from the University of Toronto. **L. H. Baxter** (A '26) formerly meter engineer in Toronto, Ontario, will fill the superintendency vacated by Mr. Looney. Mr. Baxter, who also is a graduate of the University of Toronto (1924), has been employed by the Commission since 1923.

J. H. Belknap (M '34) lieutenant colonel on duty with the United States Army Air Forces, Washington, D. C., has been appointed chairman of the newly established division of engineering of the University of Rochester, N. Y. Colonel Belknap will be Yates professor of electrical engineering. A 1912 graduate of Oregon State College, Corvallis, Colonel Belknap taught at that institution, except during World War I, until 1923. He was associated with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., from 1923 until in 1942 he was commissioned a major in the Air Corps to serve as a member of the AAF Officer Appointment Board. He is a member of the laboratories of the National Advisory Committee for Aeronautics and has received a commendation from General Ira Eaker for his work as a member of a special military mission to the United Kingdom.

Zay Jeffries (M '36, F '42) vice-president in charge of the chemical department of the General Electric Company, Pittsfield, Mass., is the first recipient of the newly established annual powder metallurgy medal of Stevens Institute of Technology, Hoboken, N. J., for "outstanding work in the field of powder metallurgy." Doctor Jeffries also has just been awarded the Francis J. Calmer Medal of the Franklin Institute which is given once every five years for achievement in the field of metallurgy for his "meritorious contributions to the science of metals, which he has placed on a new and more intelligent basis."

R. E. Blasen (A '34) recently retired as lieutenant colonel in the United States Army Corps of Engineers, has been appointed application engineer for the San Diego, Calif., area by the Westinghouse Electric and Manufacturing Company. A 1933 graduate of Oregon State College, Mr. Blasen joined the Westinghouse Company in 1936 and after assignments in East Pittsburgh, Pa., and in Seattle and Spokane, Wash., was transferred to Los Angeles, Calif., in 1940. He entered active service as a first lieutenant in 1941 and participated in the North African, Sicilian, and Italian campaigns.

N. A. Rollins (M '27, F '40) staff engineer, engineering department, Commonwealth Edison Company, Chicago, Ill., recently

retired. Mr. Rollins attended New Hampshire College and in 1904 entered the employ of the Edison Company as a draftsman. He was made field engineer in 1927 and in 1935 as plant installation engineer was put in charge of the installation of all the station, substation, and outside plant equipment for the company. He became staff engineer in 1943.

A. M. Garrett (A '22, M '40) staff engineer, engineering department, Commonwealth Edison Company, Chicago, Ill., recently retired. Mr. Garrett received the degree of bachelor of science in electrical engineerng from Purdue University in 1904 and was employed by the Commonwealth Edison Company as a draftsman in 1907. Progressing through various design and construction duties he became a field engineer in 1927 and as such was in charge of substation design and installation. In 1937 he was named staff engineer.

V. M. Marquis (A '23, M '31) formerly of the engineering department of the American Gas and Electric System, New York, N. Y., has been named director of the Office of War Utilities' power division. Mr. Marquis was graduated from Stanford University in 1921 and received the degree of master of science from Union College. He was associated with the General Electric Company, Schenectady, N. Y., until 1927 and had been with the American Gas and Electric System since 1928.

C. R. Hanna (A '24, M '39) formerly manager of the electrochemical department, research laboratories, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has become an associate director of the laboratories. Mr. Hanna, who holds two engineering degrees from Purdue University, entered the research department of the Westinghouse Company in 1922 and became manager of the development division in 1923 and of the electromechanical division in 1930.

F. X. Lamb (A '36) formerly development engineer, electrical-engineering department, Weston Electrical Instrument Corporation, Newark, N. J., has been made assistant chief electrical engineer. Mr. Lamb joined the Weston Corporation in 1921, and in 1928 organized and became head of the commercial division of the engineering department. In 1937 he went to the Orient as resident engineer, returning and becoming division chief in 1939 and project engineer in 1942.

Edward Allen (A '40) formerly editor, *Electric Light and Power*, Chicago, Ill., has been appointed general service engineer, Electric Power Board of Chattanooga, Tenn. Mr. Allen was graduated from Louisiana State University in 1925 and after an association with the Public Service Company of Northern Illinois, Chicago, joined *Electric Light and Power* as engineering editor in 1937. Since 1940 he had been editor in chief.

M. E. Bretschneider (A '32, M '39) formerly foreman of the laboratory, Kansas City (Mo.) Power and Light Company, has been made assistant superintendent of meters and laboratory. **Clarence Sloan** (A '41) of the company's laboratory will succeed as foreman. **K. W. Koso** (A '32) formerly foreman of electrical maintenance, has been appointed assistant electrical engineer of power plant.

E. S. Coffman (A '34) formerly senior engineer, bureau of electrical engineering, Federal Power Commission, Washington, D. C., has been appointed chief of the division of rates and research. Mr. Coffman was associated with the Public Service Commission of Indiana and the Power Authority of the State of New York before joining the Federal Power Commission in 1933.

H. B. Marvin (A '20, M '43) formerly assistant engineer, in the general engineering laboratory of the General Electric Company, Schenectady, N. Y., will be responsible for special assignments in the company's tube division of the electronics department. Mr. Marvin, who holds the bachelor's and master's degrees in electrical engineering from Union College, has been associated with the company since 1915.

V. G. Muznay (A '38) associate engineer, Northeastern inspective district, Bonneville Power Administration, Schenectady, N. Y., has been appointed electrical engineer, consultant, and technical adviser for the Administration's Puget Sound district office. Mr. Muznay, who was born and educated in Czechoslovakia, formerly was chief electrical-engineering draftsman for the Fourth Naval District, Philadelphia, Pa.

L. P. Haner (A '41) formerly engineer in the rayon pioneering research section of E. I. du Pont de Nemours and Company, Buffalo, N. Y., has been transferred to the rayon engineering section of the company to establish an electronics group. Mr. Haner, who graduated from the University of Washington in 1937, has been with the du Pont Company since 1939.

John Hutchings (A '36, M '43) chief engineer, Continental Electric Company, Geneva, Ill., has been appointed vice-president in charge of engineering. After his graduation from the University of Nebraska in 1933, he joined the General Electric Company, Schenectady, N. Y., in 1934. In 1942 he became chief engineer of the Continental Electric Company.

A. G. L. McNaughton (A '11, HM '42) recently named a Canadian Defense Minister and formerly lieutenant general and commander in chief of the Canadian Active Service Forces, has been promoted to the rank of full general and retired from the Canadian Army. General McNaughton is the fourth Canadian to be honored with this rank.

R. G. Slauer (A '41) formerly in the commercial engineering department of the lamp division of the Westinghouse Electric and Manufacturing Company, Bloomfield, N. J., has become manager of the application, laboratory of Sylvania Electric Products Inc., Salem, Mass. Mr. Slauer had been associated with the Westinghouse Company since 1930.

R. B. Lattin (A '36) formerly factory manager, Rockbestos Products Corporation, New Haven, Conn., has been appointed technical director. Mr. Lattin, who joined the company as research engineer in 1932, previously had been associated with the Johns Pratt division of the Colts Patent Fire Arms Manufacturing Company, Hartford, Conn.

W. F. Hess (A '32, M '41) associate professor and head of the welding laboratory, Rensselaer Polytechnic Institute, Troy, N. Y., has been awarded the Lincoln Gold Medal of the American Welding Society in conjunction with W. C. Herrschaft as the authors of a paper representing the greatest contribution to the advancement and use of welding for the year 1944.

E. W. Spring (A '26, M '32) engineer, electrical system, Detroit (Mich.) Edison Company, is on leave of absence from that company to serve as engineer for the Detroit Metropolitan Aviation Planning Authority. Mr. Spring is liason between the Michigan Aeronautics Authority and the firms which are conducting its regional airport survey.

F. B. Jewett (A '03, F '12) chairman of the National Defense Research Committee, who has just retired as vice-president of the American Telephone and Telegraph Company, New York, N. Y., recently was elected an honorary member of the New York Electrical Society.

Gano Dunn (A '91, F '12) president of the J. G. White Engineering Corporation, New York, N. Y., recently was made an honorary member of the American Society of Mechanical Engineers and of the New York Electrical Society.

G. W. Lawrence (A '19) president, Sangamo Company, Ltd., Leaside, Ontario, Canada, has been elected to the provisional board of directors of the lately founded Canadian Electrical Manufacturers' Association.

D. S. Young (A '28, M '36) formerly district engineer, Anaconda Wire and Cable Company, Chicago, Ill., has joined the staff of the Canada Wire and Cable Company, Ltd., Toronto, Ontario, Canada, as development engineer.

C. C. Sowards (A '40) captain in the Ordnance Department, United States Army, Milwaukee (Wis.) Ordnance Plant, has been relieved of active duty and will return to his position with the Copperweld Steel Company, Glassport, Pa.

K. G. Kempf (A '43) formerly district manager, Thomas Betts and Company, Los Angeles, Calif., has been appointed Pacific Coast manager for the company with which he has been associated since 1935.

Maurice Holland (A '23, M '30) industrial research adviser, New York, N. Y., has been appointed industrial research adviser to the Midwest Research Institute, Kansas City, Mo.

L. E. Messinger (A '30) president, Line Materials, Ltd., Toronto, Ontario, Canada, has been elected treasurer of the new Canadian Electrical Manufacturers' Association.

C. P. Christensen (A '14) formerly engineer in charge of installation of electric units, Grand Coulee Dam, Wash., recently was made director of power at Boulder Dam, Nev.

Sir Standen L. Pearce (A '08, F '12) engineer-in-chief, London (England) Power Company, Ltd., has been elected to honorary membership in the American Society of Mechanical Engineers.

J. B. Kearney, Jr. (M '25) chairman of the board, James R. Kearney Corporation, St. Louis, Mo., has been elected president of the National Industrial Advertisers Association.

C. L. Collens, 2nd (A '07, M '40) formerly president of the Reliance Electric and Engineering Company, Cleveland, Ohio, has become chairman of the board for the company.

J. B. Clapp (A '24, M '36) formerly sales engineer, James R. Kearney Corporation, New York, N. Y., now is associated with Thomas and Betts Company, Elizabeth, N. J.

OBITUARY

Alfred Cookman Marshall (A '14, F '29) director, consultant, and chairman of the operating council of The Detroit (Mich.) Edison Company, died February 9, 1945. Mr. Marshall, who was born in Middletown, Ohio, September 26, 1872, was graduated from the University of Michigan in 1893 with the degree of bachelor of science in electrical engineering. He also held the honorary degrees of master of science from the University of Michigan (1932) and of doctor of arts from Wayne University (1934). Mr. Marshall was employed first by the Public Lighting Commission of the City of Detroit from 1894 until 1899 when he became chief engineer of the Rapid Railway System. He left the latter position in 1904 to become engineer on construction work for The Detroit Edison Company and in 1905 was appointed general manager of the Port Huron Light and Power Company. In 1911 he was elected assistant to the president of the Eastern Michigan Edison Company and in 1912 a vice-president of the Detroit Edison Company. In addition he was named general manager in 1921 and president and general manager in 1940. He retired as president in 1944. He had been a director of the company since 1920. Active in civic life, Mr. Marshall was a member of the Board of Water Commissioners of the City of Detroit from 1925 to 1926 and served as liquidating trustee of the Detroit Trust Company from 1933 to 1940. He was elected a director of the Federal Reserve Bank of Chicago in 1935, and also had served as president and trustee of the Detroit Bureau of Governmental Research, vice-president of the Detroit Industrial Safety Council, member of the Advisory Board of the Salvation Army, member of the advisory council of the Detroit Citizens League, member of the board of directors of the Detroit Community Fund and the Committee on City Audit, president and permanent trustee of the Rackham Engineering Foundation, and trustee of the Wayne University Foundation and of Harper Hospital. He was a member of the American Society of Civil Engineers, the Engineering Society of Detroit, the United States Chamber of Commerce, and the executive committee of the Association of Edison Illuminating Companies.

John Dudley Ball (A '11, M '13, F '20) professor of physics, Mount Mary College, Milwaukee, Wis., died February 10, 1945. Doctor Ball, who was born December 8, 1882, in Seneca, Ill., was graduated from the University of Illinois with the degree of bachelor of science in 1907 and received the degree of electrical engineer in 1915. From Marquette University he received the degree of doctor of philosophy in 1928. He entered the test department of the General Electric Company, Schenectady, N. Y., in 1907 and later was transferred to the standardizing laboratory and the consulting engineering department. During this time he was associated with C. P. Steinmetz in the development of silicon steels. In 1917 he joined the Milwaukee School of Engineering as professor of electrical engineering and served as dean from 1918 to 1920 and educational director from 1926 to 1934. Since 1933 he had been professor of physics and business administration at Mount Mary College. For his work in electromagnetism he was awarded the Edward Longstreth Medal of the Franklin Institute for 1916, and he was the author of many technical papers in both English and German. He once was conductor of the General Electric Symphony Orchestra. Doctor Ball was a many-sided participant in community life and served as president of the first Mayor's Advisory Council and of the Milwaukee Civic Commission and as member of the Engineers' Examining Board of the City of Milwaukee. He was a past president of the Engineers' Society of Milwaukee, past chairman of the AIEE Milwaukee Section, and a fellow of the American Association for the Advancement of Science.

Raymond Sterling Kelsch (A '02, M '03, F '12) retired consulting engineer, and former AIEE vice-president (1918–19), died February 4, 1945, in Montreal, Quebec, Canada. He was born May 19, 1862, in Chicago, Ill., and studied at the Armour Institute. He was repairman, operator, assistant manager, manager, and division superintendent for the American District Telegraph and Telephone Company, later the Chicago Telephone Company, from 1877 to 1883. Thereafter he was station superintendent and general superintendent for the Chicago Arc Light and Power Company and, when in 1893 the company was absorbed by the Chicago Edison Company, he was appointed superintendent of high-voltage systems. In 1897 he resigned to become general superintendent and engineer of the Lachine Rapids Hydraulic and Land Company, Ltd., Montreal. After 1903 Mr. Kelsch practiced privately as a consulting engineer, and as such had been retained until his death by the former Montreal Light, Heat and Power Consolidated Company. He retired in 1926. He was a commissioner of Montreal's Electrical Service Commission, a member and past president of the Canadian Electrical Association, a member of the Institution of Electrical Engineers, the Professional Engineers of the Province of Quebec, and a member and one-time councilor of the Engineering Institute of Canada. He was elected honorary chairman of the new AIEE Montreal Section in 1943.

Hugh Alexander Brown (A '16, M '26) professor of electrical engineering, University of Illinois, Urbana, died February 25, 1945. Born in Cedar Springs, Pa., June 19, 1889, Professor Brown received the degrees of bachelor of science in 1911, master of science in 1913, and electrical engineer in 1915 from the University of Illinois. After a short employment with the General Electric Company, Schenectady, N. Y., and the Illinois Traction System, Peoria, he commenced his teaching career as instructor at the University of Arkansas, Fayettesville, in 1916. He was on the staff of the United States School of Military Aeronautics in 1917, Ottawa (Kans.) University in 1919, and of Pennsylvania State College in 1920. He joined the faculty of the University of Illinois in 1921. Professor Brown instituted the courses in radio engineering at the University and was the inventer of an alkali-vapor detector tube and the discoverer of a new method of testing insulation. He was the author of "Radio-Frequency Electrical Measurements," a textbook, as well as other popular articles. He was a member of the Institute of Radio Engineers and the Society for the Promotion of Engineering Education.

George Kimball Manson (A '09, F '23) retired chief engineer, New England Telephone and Telegraph Company, Boston, Mass., died in Brookline, Mass., January 6, 1945. Born April 4, 1876, in East Haverhill, N. H., Mr. Manson was graduated from Phillips Exeter Academy in 1894. His entire engineering career was spent with the New England Telephone Company for which he started work as a night operator in 1891. He was appointed assistant in the office of the electrical engineer in 1898, assistant electrical engineer in 1900, assistant chief engineer in 1902, engineer in 1905, and chief engineer in 1912. Mr. Manson supervised the design and building of most of the company's central telephone offices, developed dial service, and planned the first ship-to-shore radiotelephone service in New England. He had served on the City of Boston Noise Commission, and the City of Boston Traffic Control Committee and was a past president of the city's Engineers Club. At his death he was president of the Franklin Foundation and was chief business consultant of the communications division of the War Production Board.

Harry Munson Warren (A '03) chief engineer, Glen Alden Coal Company, Scranton, Pa., died February 3, 1945. He was born November 22, 1875, in Worcester, Mass., and was graduated from Worcester Polytechnic Institute in 1896. After a brief period with the General Electric Company, Schenectady, N. Y., he entered the coal mining department of the Delaware Lackawanna and Western Railway Company, Scranton, and in 1921 became consulting engineer for the Glen Alden Company. He also was electrical engineer of the Key-

stone Mining Company. He was a member of a commission appointed by Theodore Roosevelt to study mining in Europe. Mr. Warren was identified prominently with the development of the use of fine-size anthracite for power production purposes and the development of the multistage centrifugal pump and the electrifying of coal breakers. Mr. Warren was a member of the United States Fuel Administration during World War I and of the American Railway Engineering Association. He was a charter member and past president of the Engineering Society of Northeastern Pennsylvania.

John Carleton Albert (A '10, M '34) assistant electrical engineer, Department of Water and Power, City of Los Angeles, Calif., died January 16, 1945. Mr. Albert was born in Lima, Ohio, June 11, 1883, and entered electrical work as an apprentice in various contracting shops about 1903. He was employed as a tester by the Jeffrey Manufacturing Company, Columbus, Ohio, and as an inspector by the Pacific Electric Railway Company, Los Angeles, before 1910. In 1910 he commenced an association as chief electrician with the Minas del Tajo, Rosario, Sinaloa, Mexico, which lasted irregularly until 1916. During this period he also was employed in the testing laboratory of the Pacific Light and Power Company, Los Angeles. In 1917 he became assistant electrical engineer in charge of the testing laboratories of the Los Angeles Bureau of Power and Light which was later absorbed by the Department of Water and Power. He retired in 1944.

MEMBERSHIP • • •

Recommended for Transfer

The board of examiners, at its meeting on March 15, 1945, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Calvert, J. F., chairman, dept. of elec. engg., Northwestern Technological Institute, Evanston, Ill.

Gonseth, J. E., asst. gen. mgr., Automatic Electric Co.; vice-pres., Associated Elec. Labs., Inc., Chicago, Ill.

Graybill, E. W., pres., Automatic Elec. Labs., Inc., Chicago, Ill.

Johnson, J. Hugo, prof. of elec. engg., University of Idaho, Moscow, Idaho

Lewis, W. A., consultant in elec. engg., Armour Research Foundation, Chicago, Ill.

Nystrom, C. W., general outside plant engr., Southwestern Bell Tel. Co., St. Louis, Mo.

Ricker, C. V., prof. and head, School of Elec. Engg., Tulane University, New Orleans, La.

7 to grade of Fellow

To Grade of Member

Blaese, A. C., Manufacturers Agent, Valparaiso, Ind.

Bottaner, S. B., elec. design engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Brown, D. L., testing engr., Portland General Elec. Co., Portland, Oreg.

Browne, F. H., sales engr., Copperweld Steel Co., New York, N. Y.

Cleaver, J. J., mgr., Public Utilities Commission, Almonte, Ont., Canada.

deBonneval, H. A., chief elec. engr., George G. Sharp, New Orleans, La.

Devine, L. V., elec. engr., Moloney Elec. Co., St. Louis, Mo.

Everhart, J. C., asst. to chief transformer engr., Line Material Co., Zanesville, Ohio.

Ewart, W. L., supt. of utilities, Lago Oil & Transport Co. Ltd., Aruba, Curacao, West Indies

Gagnier, G. E., elec. design engr., North American Aviation, Inc., Inglewood, Calif.

Gould, E. H., Lieut. Comdr., USNR, Mare Island Navy Yard, Calif.

Haun, B. O., engr., Emerson Electric Mfg. Co., St. Louis, Mo.

Heffernan, J. A., elec. engg. asst., Public Service Elec. & Gas Co., Newark, N. J.

Johnson, J. S., elec. engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Lapsley, R. P., Lieut. Colonel, Chief of Electrical Section, U. S. Engineers, Atlanta, Ga.

Leake, W. S., sales engr., General Elec. Co., New Orleans, La.

MacDowell, M., engg. and service supervisor, Westinghouse Elec. & Mfg. Co., Portland, Oreg.

Madison, E. A., vice-pres., The Starbuck Sprague Co., Waterbury, Conn.

Martz, C. J., chief engr., City of Huntsville Electric System, Huntsville, Ala.

McCarty, W. R., elec. engr., Wagner Elec. Corp., St. Louis, Mo.

McLeod, L. W., central station division mgr., Westinghouse Elec. & Mfg. Co., St. Louis, Mo.

Meissner, E. R., president and general mgr., St. Louis Aircraft Corp., St. Louis, Mo.

Moore, J. F., elec. engr., Dunlop Tire & Rubber Goods Co. Ltd., Toronto, Ont., Canada.

Morton, L. W., rectifier application engr., General Elec. Co., Schenectady, N. Y.

Munier, R. F., chief motor engr., Emerson Elec. Mfg. Co., St. Louis, Mo.

Nelson, H. R., asst. plant supt., Tennessee Valley Authority, Guntersville, Ala.

Peterson, A. P., president, Control Corp., Minneapolis, Minn.

Phillips, W. R., elec. engr., Moloney Elec. Co., St. Louis, Mo.

Rohlfsen, A. G., elec. supervisor, Johns-Manville, Los Angeles, Calif.

Rothus, E. A., design engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Schoetker, R. W., substation engr., Union Elec. Co. of Missouri, St. Louis, Mo.

Seybt, H. B., sales engr., General Elec. Co., St. Louis, Mo.

Sidenfaden, O. L., elec. engr., Dept. of Water & Power, Los Angeles, Calif.

Somerville, J. M., chief engr., Canadian Porcelain Co. Ltd., Hamilton, Ont., Canada.

Stanwix-Hay, Walter, commercial engr., General Elec. Co., Bridgeport, Conn.

Steensen, A. P., engr., The Foxboro Co., Foxboro, Mass.

Stock, H. F., asst. elec. engr., Pratt & Whitney Aircraft Corp. of Missouri, Kansas City, Mo.

Stodola, E. K., engr., Camp Evans Signal Laboratory, Belmar, N. J.

Whiteley, Eric, asst. D. C. engr., Canadian General Elec. Co. Ltd., Peterborough, Ont., Canada

39 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the national secretary before May 15, 1945 or July 15, 1945, if the applicant resides outside of the United States or Canada.

To Grade of Member

Alioto, J. J., Globe-Union, Inc., Milwaukee, Wis.

Alvarado, G., Worthington Pump & Mchy. Corp., Harrison, N. J.

Anderson, D., Southern Can. Pr. Co., Ltd., Montreal, Que., Can.

Antes, L. L., Univ. of Texas, Austin, Tex.

Arkhangelsky, G. D., Pur. Com., U.S.S.R., New York, N. Y.

Arstad, L. O., Northwestern Bell Tel. Co., Des Moines, Iowa

Ayers, E. H. (Reelection), Gen. Elec. Co., Schenectady, N. Y.

Ayres, A. F. (Reelection), Calif. Elec. Pr. Co., Riverside, Calif.

Banan, H. F. (Reelection), Elec. Machinery Mfg. Co., New York, N. Y.

Bedl, R. S. (Reelection), Diesel Power Station, Simla, India

Bird, J. R., Bird Engg. Co., Cleveland, Ohio

Boswell, C. C., Minn. Pr. & Lt. Co., Duluth, Minn.

Briere, J. (Reelection), Ayrshire Collieries Corp., Indianapolis, Ind.

Burns, R., Whitehead Iron & Steel Co., Ltd., Newport, Wales

Cline, V. F. (Reelection), Univ. of Mich., Ann Arbor, Mich.

Colburn, A. R. (Reelection), Rural Elec. Adm., St. Louis, Mo.

Cook, E. R., RAF, Alresford, England

Crago, H. R., Gen. Elec. Co., Schenectady, N. Y.

Dauenhauer, C. M., Kellex Corp., Knoxville, Tenn.

Ellis, J. L. (Reelection), Lieut. Comdr., U.S.N.R., Annapolis, Md.

Fannon, J. L. (Reelection), Stone & Webster Engg. Corp., Boston, Mass.

Gallagher, J. D. (Reelection), Hartford Accid. & Indem. Co., Chicago, Ill.

Gardner, E. R. (Reelection), Gen. Elec. Co., W. Lynn, Mass.

Hall, R. S., Jr., Captain, U. S. Army, Fort Lewis, Wash.

Harden, J. C., S. C. Elec. & Gas Co., Columbia, S. C.

Harder, A. W., Lieut. (jg), U.S.N.R., Dallas, Tex.

Harvey, D. A. (Reelection), Patent Lawyer, St. Louis, Mo.

Heston, W. C. (Reelection), "Electrical West," San Francisco, Calif.

Hugon, J., French Supply Mission, Washington, D. C.

Jones, W. (Reelection), National Elec. Prod. Corp., Pittsburgh, Pa.

Jordan, T. (Reelection), Amer. Smelt. & Ref. Co., Garfield, Utah.

Kaspar, A. A. (Reelection), Laclede Pr. & Lt. Co., St. Louis, Mo.

Kirillow, E. V., Pur. Com., U.S.S.R., New York, N. Y.

Kurtz, J. (Reelection), International Smelting & Ref. Co., Tooele, Utah

Lang, C. M., Tenn. Val. Auth., Knoxville, Tenn.

Langelier, G., A. A. Jones Const. Co., Brunswick, Ga.

Lenz, G. J. (Reelection), Cutler-Hammer, Inc., Milwaukee, Wis.

Lix-Klett, E. (Reelection), E. Lix-Klett & Co., Buenos Aires, Arg., S. A.

Martinez, J. B., Reynolds Elec. & Engg. Co., Inc., El Paso, Tex.

Miller, E. P., S. C. Elec. & Gas Co., Columbia, S. C.

Morris, R. V. (Reelection), Northern Ind. Pub. Serv. Co., Gary, Ind.

Murray, J. A., Douglas Aircraft Co., Inc., Santa Monica, Calif.

Negley, S. R., Reading Co., Philadelphia, Pa.

Nicholson, J. R. (Reelection), Gen. Elec. Co., New York, N. Y.

Onder, K., Com. Equip. Corp., Pasadena, Calif.

Palmquist, J. F., Don Lee Broadcast., Inc., Hollywood, Calif.

Patton, L. E., Cons. Engr., San Francisco, Calif.

Pignolet, L. W. (Reelection), Weston Elec. Inst. Corp., Newark, N. J.

Pullinger, W. W., Lieut. R.C.N.V.R., Ottawa, Ont., Can.

Roberts, F. W., Crompton Parkinson, Ltd., Chelmsford, England

Schwartz, N. J., Heinemann Circuit Breaker Co., Trenton, N. J.

Siegel, D. T., Obmite Mfg. Co., Chicago, Ill.

Starcke, M., Lower Colo. River Auth., Austin, Tex.

Stayner, C. M. (Reelection), Union Pacific R.R., Salt Lake City, Utah

Stephens, W. P., National Sup. Co., Springfield, Ohio

Warren, C. A. (Reelection), Portland Gen. Elec. Co., Portland, Oreg.

Waterman, A. L., Dartmouth Col., Hanover, N. H.

Williams, A. L. (Reelection), Great Lakes Carbon Corp., Niagara Falls, N. Y.

58 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Azua, R. V., Jr., Intl. Gen. Elec. Co., Schenectady, N. Y.

Berg, L. D. T., Gen. Elec. Co., Schenectady, N. Y.

Chabal, V. W., Gen. Elec. Co., Syracuse, N. Y.

Chapman, G. H. (Reelection), Gen. Elec. Co., Schenectady, N. Y.

Cooper, J. D., Stromberg-Carlson Co., Rochester, N. Y.

Cummings, J. D., Gen. Elec. Co., Schenectady, N. Y.

Davis, M. E., Gen. Elec. Co., Schenectady, N. Y.

del Palacio, J., Gen. Elec. Co., Schenectady, N. Y.

Demartini, R. J., Gen. Elec. Co., Schenectady, N. Y.

D'Entremont, F. R., Gen. Elec. Co., Lynn, Mass.

Dixon, E. O., Eastman Kodak Co., Rochester, N. Y.

Duryea, J. B., Gen. Elec. Co., Schenectady, N. Y.

Edgerly, A. H., A. S. Mancib Co., West Somerville, Mass.

Fairley, R. K., Gen. Elec. Co., Schenectady, N. Y.

Fink, W. A., Stromberg-Carlson Co., Rochester, N. Y.

Franck, R. E., Gen. Elec. Co., Lynn, Mass.

Friedman, H. M., Gen. Elec. Co., Schenectady, N. Y.

Gillespie, H., Gen. Elec. Co., Schenectady, N. Y.

Glasman, A., Gen. Elec. Co., Schenectady, N. Y.

Hausler, G. M., Gen. Elec. Co., Schenectady, N. Y.

Holt, J. W., Jr., Gen. Elec. Co., Schenectady, N. Y.

Horton, M., Gen. Elec. Co., Schenectady, N. Y.

Hutchinson, H. H., Gen. Elec. Co., Schenectady, N. Y.

Hyman, B., Sylvania Elec. Prod., Inc., Salem, Mass.

Juengst, F. H., Eastman Kodak Co., Rochester, N. Y.

Kelley, F. W., Jr., Gen. Elec. Co., Schenectady, N. Y.

Kelly, L. J., Gen. Elec. Co., Lynn, Mass.

Kemnitz, W. N., Gen. Elec. Co., Schenectady, N. Y.

Knapp, G. W., Gen. Elec. Co., Schenectady, N. Y.

Kranz, H. P., Narragansett Elec. Co., Providence, R. I.

Larkin, T. E., Gen. Elec. Co., Schenectady, N. Y.

Lemmo, R. J., Maguire Ind., Greenwich, Conn.

Lyon, R. P., Stromberg-Carlson Co., Rochester, N. Y.

Mander, E. E., Jr., Gen. Elec. Co., Schenectady, N. Y.

Midgley, P. L., Gen. Elec. Co., Schenectady, N. Y.

Moore, R. B., Gen. Elec. Co., Schenectady, N. Y.

Mosby, A. M., Intl. Gen. Elec. Co., Schenectady, N. Y.

Petrake, K. A., Gen. Elec. Co., Schenectady, N. Y.

Plaisted, G. E. (Reelection), Gen. Elec. Co., Schenectady, N. Y.

Pionsky, A. W., Mass. Inst. of Tech., Cambridge, Mass.

Popper, H., Gen. Elec. Co., Schenectady, N. Y.

Raney, E. A., Gen. Elec. Co., Pittsfield, Mass.

Reagan, L. H., Stromberg-Carlson Co., Rochester, N. Y.

Reehl, G. H., Gen. Elec. Co., Schenectady, N. Y.

Reese, D. R., Gen. Elec. Co., Schenectady, N. Y.

Reeves, F. E., Elec. Apparatus Co., Boston, Mass.

Ridgley, C. H., Gen. Elec. Co., Lynn, Mass.

Ridley, W. H., Jr., Stromberg-Carlson Co., Rochester, N. Y.

Rockwell, R. L., Gen. Elec. Co., Schenectady, N. Y.

Sachs, S. I., Maguire Ind., Inc., Greenwich, Conn.

Sammons, W. L., Gen. Elec. Co., Schenectady, N. Y.

Schwartz, S., Gen. Elec. Co., Schenectady, N. Y.

Smith, D. R., Sr., Gen. Elec. Co., Schenectady, N. Y.

Smoot, E. F., Gen. Elec. Co., Schenectady, N. Y.

Snady, H. W., Intl. Gen. Elec. Co., Schenectady, N. Y.

Sowell, P. B., Gen. Elec. Co., Schenectady, N. Y.

Swindells, N. M., Blackstone Val. Gas & Elec. Co., Pawtucket, R. I.

Thomas, W. T., Gen. Elec. Co., Schenectady, N. Y.

Tuer, I. M., Mass. Inst. of Tech., Cambridge, Mass.

Turrentine, F. R., Gen. Elec. Co., Schenectady, N. Y.

Wheeling, R. F., Eastman Kodak Co., Rochester, N. Y.
Whitelesey, S. L., Gen. Elec. Co., Schenectady, N. Y.
Williams, J. E., Gen. Elec. Co., Schenectady, N. Y.
Williamson, S. H., Gen. Elec. Co., Schenectady, N. Y.
Wilson, G. A., Jr., Mass. Inst. of Tech., Cambridge, Mass.
Yasi, J. W., Gen. Elec. Co., Lynn, Mass.
Yeaton, A. G., Sylvania Elec. Prod., Inc., Dover, N. H.
Zachary, R. A., Jr., Gen. Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Allen, C. E., Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Baranetski, S., Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa.
Beck, R. E., Jr., U. S. Army, Ohio State Univ., Columbus, Ohio
Benowitz, S., Westinghouse Elec. & Mfg. Co., Cleveland, Ohio
Block, H. S., Nat. Bur. of Standards, Washington, D. C.
Bromley, R. W., Bureau of Ships, Washington, D. C.
Brown, F. D., Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Brumfield, F. E., Ohio Bell Tel. Co., Cleveland, Ohio
Bulley, J. R., Gen. Elec. Co., Erie, Pa.
Cackrum, C. A., Lear, Inc., Piqua, Ohio
Corcoran, C. S., Jr., N.A.C.A., Cleveland, Ohio
Corporon, R. P., Radio Corp. of America, Camden, N. J.
Davis, D. H., Henry J. Kunzig, Baltimore, Md.
Di Meglio, M., Philco Corp., Philadelphia, Pa.
Dunn, M. M., Lear, Inc., Piqua, Ohio
Epstein, A. S., Radio Corp. of America, Camden, N. J.
Erisman, J., Lear, Inc., Piqua, Ohio
Foulks, E. C., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Galeski, R. J., N.A.C.A., Cleveland, Ohio
Gilbert, D. K., Leland Elec. Co., Dayton, Ohio
Gilleo, M. A., U. S. Navy Dept., Washington, D. C.
Hampton, W. C., Lieut., M.B.E.R.N., Washington, D. C.
Hennes, W. P., Koppers Co., Inc., Monaca, Pa.
Hess, R. D., Lear, Inc., Piqua, Ohio
Hunt, R. A., Cleveland Elec. Illum. Co., Cleveland, Ohio
Inskeep, M. J., Lear, Inc., Piqua, Ohio
Ireland, R. A., Jr., N.A.C.A., Cleveland, Ohio
Jachym, T. M., Lieut., AAF, Wright Field, Dayton, Ohio
Jeakins, J. W., Gen. Elec. Co., Philadelphia, Pa.
Johnson, B. W., Oliver Iron & Steel Corp., Pittsburgh, Pa.
Koenig, J. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Lange, A. O., James G. Biddle Co., Philadelphia, Pa.
Long, W. A., Intl., Min. & Chem. Corp., Rossford, Ohio
Lynch, E. F., Diamond Alkali Co., Painesville, Ohio
MacArthur, A., Jr., P-V Engg. Forum, Sharon Hill, Pa.
Martindale, H. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
McCowen, W. E., Radio Corp. of America, Camden, N. J.
McCullough, S., N.A.C.A., Cleveland, Ohio
Michael, P. H., U. S. Navy, Mansfield, Ohio
Mikell, W. G., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Myers, C. R., III, Radio Corp. of America, Camden, N. J.
Newberry, D. A., Ensign, U.S.N.R., Columbus, Ohio
Nippert, Gen. Elec. Co., Erie, Pa.
Odishaw, H., Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa.
Poffenberger, C. O., Gen. Elec. Co., Baltimore, Md.
Radenheimer, L. B., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Royer, C. E., Cleveland Elec. Illum. Co., Cleveland, Ohio
Silverio, V. J., Gen. Elec. Co., Philadelphia, Pa.
Stark, D. E., Stupakoff Cer. & Mfg. Co., Latrobe, Pa.
Stegman, W. L., U.S.C.G., Baltimore, Md.
Stitelman, J., U. S. Civil Serv. Comm., Washington, D. C.
Vogeley, C. E., Jr., Westinghouse Res. Lab., East Pittsburgh, Pa.
Ward, S. A., U. S. Naval Res. Lab., Washington, D. C.
Wells, M., Bird Engg. Co., Cleveland, Ohio
Woolley, J., Antioch Foundry, Yellow Springs, Ohio

3. New York City

Astrain, S., Corp. de Fom. de la Prod. of Chile, New York, N. Y.
Baker, G. H., Bell Tel. Labs., Inc., New York, N. Y.
Blackburne, T. F., Electronic Labs., Inc., New York, N. Y.
Bourquin, J. L., Jr., Sperry Gyroscope Co., Garden City, N. Y.
Casey, E. J., National Union Radio Corp., Newark, N. J.
Clinkenbeard, E. L., Western Union Tel. Co., New York, N. Y.
Coughlin, J. J., U. S. Navy Yard, Brooklyn, N. Y.
DeVebre, A. W., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Devers, W. J., Allis-Chalmers Mfg. Co., New York, N. Y.
Eder, W. L., Cons. Shipbldg. Corp., New York, N. Y.
Escoffery, A. L., Westinghouse Elec. Intl. Co., New York, N. Y.
Fry, M., W. L. Maxson Corp., New York, N. Y.
Fung, K. W., Bell Tel. Labs., Inc., New York, N. Y.
Gambuti, F. J., Wright Aero Corp., Woodridge, N. J.
Hawkins, L. N. A., Sylvania Elec. Prod., Inc., New York, N. Y.
Kern, R. E., Curtiss-Wright Corp., Caldwell, N. J.
Klay, A. M., Western Elec. Co., New York, N. Y.
Kunes, B. R., U.S.A.A.F., New York, N. Y.
Lawton, B. E., Westinghouse Elec. & Mfg. Co., Bloomfield, N. J.
Littell, J. G., Natl. Union Radio Corp., Newark, N. J.
Mapp, J., Midshipman, U.S.N.R., Brooklyn, N. Y.
Mayer, C. R., Sonotone Corp., Elmsford, N. Y.
Mazzitelli, G. A., J. A. Tuck, Consultant, New York, N. Y.
Menzel, H. R., Sperry Gyro. Co., Inc., Garden City, N. Y.
Mullally, J. W., Anaconda Wire & Cable Co., New York, N. Y.
Nittoli, V. A., U. S. Army, Flushing, N. Y.
Orowski, S. H., Pan American Airways, Jackson Heights, N. Y.
Petruska, J. M., Wright Aero. Corp., Woodridge, N. J.
Quirke, J. F., Westinghouse Elec. Elev. Co., Jersey City, N. J.
Rapetti, E. J., Arma Corp., Brooklyn, N. Y.
Rivera, E., Kelles Corp., New York, N. Y.
Stark, O. C., Square D Co., New York, N. Y.
Storch, H., Fed. Tel. & Radio Labs., New York, N. Y.
Stroup, L., Bendix Avia. Corp., Brooklyn, N. Y.
Swanson, E. H., Radio Engg. Labs., Inc., Long Island City, N. Y.
Tyne (Mrs.) G. H., Allied Control Co., Inc., New York, N. Y.
Wellen, S. D., Empire Elec. Brake Co., Newark, N. J.
White, J. H. F., Westchester Lighting Co., Pleasantville, N. Y.
White, N. N., Western Elec. Co., Kearny, N. J.
Zywotow, S. J., Western Elec. Co., Jersey City, N. J.

4. Southern

Berg, A. A., Tenn. Eastman Corp., Knoxville, Tenn.
Brems, A., Republic Min. & Mfg. Co., Bauxite, Ark.
Brock, T. R., Gen. Elec. Co., Knoxville, Tenn.
Brown, H. B., Jr., Carbide & Carbon Chem. Corp., Oak Ridge, Tenn.
Campbell, C. E., Tenn. Eastman Corp., Oak Ridge, Tenn.
Colon, C. M., Southwestern Gas & Elec. Co., Shreveport, La.
Dukes, R. C., Lieut., U.S.N.R., Charleston, S. C.
Fagan, E. M., Lt. Col., U.S.A.A.F., Little Rock, Ark.
Harvey, G. L., Carbon & Carbide Chem. Corp., Oak Ridge, Tenn.
Lockwood, J. A., Tenn. Eastman Corp., Oak Ridge, Tenn.
McAllister, P. F., N.A.C.A., Langley Field, Va.
Murray, J. G., N.A.C.A., Langley Field, Va.
Nuchols, J. N., Carbide & Carbon Chem. Corp., Oak Ridge, Tenn.
Penuel, S. S., S-2/c, U. S. Navy, Birmingham, Ala.
Rutherford, H. L., Carbide & Carbon Chem. Corp., Oak Ridge, Tenn.
Scott, R. S., Watson Flagg Engg. Co., Oak Ridge, Tenn.
Seldon, M. R., N.A.C.A., Langley Field, Va.
Smith, G. C., Jr., Carbide & Carbon Chem. Corp., Oak Ridge, Tenn.
Steele, G. R., Gen. Elec. Co., Norfolk, Va.
Sullivan, D. F., Tenn. Eastman Corp., Oak Ridge, Tenn.
Tarlton, S. L., Rayonier, Inc., Fernandina, Fla.
Thagard, G. S., Gen. Elec. Co., Knoxville, Tenn.
Willoch, H. (Reelection), Tenn. Val. Auth., Chattanooga, Tenn.

5. Great Lakes

Baerwald, H. J., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Beter, R. H., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Bosse, P. J., Northern Ind. Pub. Serv. Co., Gary, Ind.
Brower, G. A., Gauler-Hammer, Inc., Milwaukee, Wis.
Buhler, C. G., A-C Spark Plug Div., Flint, Mich.
Burleigh, S. A., Vickers, Inc., Detroit, Mich.
Christensen, R. T., Zenith Radio Corp., Chicago, Ill.
Comings, W. E., Minneapolis-Honeywell Reg. Co., Minneapolis, Minn.
Cory, H. W., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Danner, R. V., Admiral Corp., Chicago, Ill.
Doescher, R. B., Northern States Pr. Co., Minneapolis, Minn.
Ebeltoft, W. H., Minneapolis-Honeywell Reg. Co., Minneapolis, Minn.
Johnson, J. F., Corn Prod. Refg. Co., Pekin, Ill.
Jones, R. J., Globe-Union, Inc., Milwaukee, Wis.
Joscelyn, W. J., Sundstrand Mach. Tool Co., Rockford, Ill.
Kelly, M., Jr., Consumers Pr. Co., Jackson, Mich.
Krueger, J., Univ. of Minn., St. Paul, Minn.
Lamons, R. P., Western Elec. Co., Chicago, Ill.
Lorenz, A. D., Western Elec. Co., Chicago, Ill.
Miller, A. V., National Elec. Coil Co., Crete, Ill.
Niksch, E. E., Allis-Chalmers Mfg. Co., West Allis, Wis.
Peeples, R. M., Allis-Chalmers Co., Milwaukee, Wis.
Reddricks, J. T., U.S.A.A.F. Depot, South Bend, Ind.
Shaltis, R., Western Elec. Co., Chicago, Ill.
Shipman, J. S., Gen. Elec. Co., Fort Wayne, Ind.
Stange, H., Jr., U. S. Rubber Co., Mishawaka, Ind.
Sturmack, L., Janette Mfg. Co., Chicago, Ill.
Voss, H. A., Moody Bible Inst., Elmhurst, Ill.
Walden, J. M., Black Hills Broadcasting Co., Rapid City, S. Dak.
Witchey, A. L., Radio Corp. of America, Indianapolis, Ind.

6. North Central

Dodd, N. M., Kaiser Ind., Inc., Denver, Colo.
Lindseth, E. V., U. S. Bur. of Rec., Denver, Colo.
Uttaut, W. F., U.S.N.R., 532 Park St., Sterling, Colo.

7. South West

Chandler, G. M., Lower Colo. River Auth., Austin, Tex.
Cobb, J. R., Rural Elec. Adm., St. Louis, Mo.
Cochell, L. A., U. S. Engineers, Houston, Tex.
Collins, E. M., Lieut., U. S. Army, Camp Crowder, Mo.
Conner, J. O., Southwestern Bell Tel. Co., Lawton, Okla.
Ellison, J. R., Okla. Gas & Elec. Co., Oklahoma City, Okla.
Francis, J. M., New Braunfels Util., New Braunfels, Tex.
Gillespie, K. T., Okla. Elec. Sup. Co., Oklahoma City, Okla.
Gordon, C. A., Southwestern Bell Tel. Co., Houston, Tex.
Heap, W. O., Schlumberger Well Sur. Corp., Houston, Tex.
Pickens, H. L., Allis-Chalmers Mfg. Co., Oklahoma City, Okla.
Redmond, W. B., U. S. Engineer, Galveston, Tex.
Robb, D. D., Univ. of Kans., Lawrence, Kans.
Shaad, D. E., Black & Veatch, Kansas City, Mo.
Simon, P. G., Gulf States Util. Co., Beaumont, Tex.
Waldner, M., McQuay-Norris Co., St. Louis, Mo.
White, A. W., A. W. White Elec. Motor & Machy. Co., Oklahoma City, Okla.

8. Pacific

Blankmann, W. L., Civil Aero. Adm., Redwood City, Calif.
Brewer, W. B., Lockheed Aircraft Corp., Burbank, Calif.
Brownfield, R. E., Bur. of Pr. & Lt., Los Angeles, Calif.
Buck, C. M., Pac. Gas & Elec. Co., San Francisco, Calif.
Clayton, G. H., Lieut., U.S.N.R., Sunset Beach, Calif.
Hall, E. S., S-1/c, U. S. Navy, San Gabriel, Calif.
Holcombe, G. B., Matson Navig. Co., San Francisco, Calif.
Jeffords, R. D., Calif. Shipbldg. Corp., Wilmington, Calif.
Lovell, A. J., Sacramento Mun. Util. Dist., Sacramento, Calif.
McLaughlin, E. F., Permanente Metals Corp., Richmond, Calif.
Morris, C., Earl S. Condon Co., Los Angeles, Calif.
Nelson, A., Dept. of Water & Power, Los Angeles, Calif.
Sather, K. M., Pac. Gas & Elec. Co., San Francisco, Calif.
Schoonover, W. L., Douglas Aircraft Co., Long Beach, Calif.
Silvey, H. R., Dept. of Water Power, Los Angeles, Calif.
Sklensky, F., Douglas Aircraft Co., Inc., Santa Monica, Calif.
Smith, H. F., Cons., Vultee Aircraft Corp., San Diego, Calif.
White, M. J., Pac. Elec. Mfg. Corp., San Francisco, Calif.
Williams, H. M., City of L. A., Los Angeles, Calif.

9. North West

Bruckner, C. G., Mont. Pr. Co., Bozeman, Mont.
Calderwood, D. S., Kaiser Co., Inc., Portland, Oreg.
Eastman, C. W., Boeing Aircraft Co., Seattle, Wash.
Elliott, D. S., Ensign, U.S.N.R., Brewster, Wash.
Griffin, B. L., Oreg. State Col., Corvallis, Oreg.
Johnson, J. H., 2323 W. Liberty Ave., Spokane 12, Wash.
Matney, T. L., Tech. Engineers Union, Local #79, Portland, Oreg.
Rogers, E. P., Bonneville Pr. Adm., Vancouver, Wash.
Smith, N. D., Naval Air Bases, Seattle, Wash.
Thurber, D. C., Goggan's & Pennie, Great Falls, Mont.
Winsor, G. C., Puget Sound Navy Yard, Bremerton, Wash.
Young, K. J., Boeing Aircraft Co., Seattle, Wash.

10. Canada

Beaton, S. J., Can. Gen. Elec. Co., Ltd., Peterboro, Ont., Can.
Cleminson, J. A. C., Victory Aircraft, Ltd., Malton, Ont., Can.
Coleman, A. B. M., Lloyds Reg. of Shipping, Vancouver, B. C., Can.
Collins, T., B. C. Elec. Ry. Co., Ltd., Vancouver, B. C., Can.
Conning, A. R., Goodyear Tire & Rubber Co., New Toronto, Ont., Can.
Elsworth, P. J., John Inglis Co., Toronto, Ont., Can.
Helliwell, R. A., Stanford University, Calif.
Jackson, R. R., Can. Gen. Elec. Co., Peterboro, Ont., Can.
Julson, O. M., Can. Gen. Elec. Co., Peterboro, Ont., Can.
Kehoe, V. P., DeHavilland Aircraft Co. Ltd. of Can., Toronto, Ont., Can.
Madryga, A., Can. Gen. Elec. Co., Ltd., Peterboro, Ont., Can.
McDiarmaid, R. B., Dept. of Transport, Dom. Govt., Edmonton, Alta., Can.
Noseworthy, F. M., Bell Tel. Co. of Can., Montreal, Que., Can.
Orlando, E. E., Can. Westinghouse Co., Ltd., Montreal, Que., Can.
Overend, A. V., Can. Marconi Co., Ltd., Mount Royal, Que., Can.
Rappel, H. T., Can. Gen. Elec. Co., Ltd., Peterboro, Ont., Can.
Rome, A. H., 5891 Alma Road, Vancouver, B. C., Can.
Stanger, E. A. (Reelection), Southern Can. Pr. Co., Ltd., Montreal, Que., Can.

Elsewhere

Amin, N. B., Jyoti, Ltd., Baroda, India
Banerjee, M. N., Hindustan Aircraft, Ltd., Bangalore, India
Fuller, F. H., H. J. Fuller & Sons, Ltd., Leeds, England
Greaves, H. A., Demerara Bauxite Co., Mackenzie City, British Guiana, S. A.
Myers, L., Guest Keen Williams, Ltd., Howrah, India
Rusterholz, H. C., Cerro-de-Pasco Copper Corp., La Oroya, Peru, S. A.
Sanders, J. C. M., Crompton-Parkinson, Ltd., Chelmsford, England
Taylor, R. L., Crompton-Parkinson, Ltd., Chelmsford, England
Torruella Soto, J. A., P. R. Water Res. Auth., Santurce, P. R.

Total to grade of Associate
United States and Canada, 285
Elsewhere, 9

OF CURRENT INTEREST

Bureau of Standards Extends Broadcast Service

The National Bureau of Standards broadcast service, which comprises the broadcasting of standard frequencies and standard time intervals from the Bureau's radio station WWV near Washington, D. C., has been slightly extended by broadcasting 15 megacycles at night as well as in the daytime.

The service is continuous at all times from ten-kilowatt radio transmitters, except on 2,500 kilocycles per second where one kilowatt is used, and includes, in addition to the frequency and time standards, standard audio frequencies, and standard musical pitch, 440 cycles per second, corresponding to A above middle C. Any desired frequency may be measured in terms of the standard frequencies with the aid of harmonics and beats, with one or more auxiliary oscillators.

The radio frequencies utilized by the National Bureau of Standards are 2.5 megacycles per second, broadcast from 7:00 p.m. to 9:00 a.m., Eastern War Time; and 5, 10, and 15 megacycles per second, broadcast continuously day and night. Moreover, there is, on all carrier frequencies, a pulse of 0.005-second duration which occurs at intervals of precisely one second. The pulse consists of five cycles, each of 0.001-second duration, and is heard as a faint tick when listening to the broadcast. This provides a standard time interval for purposes of physical measurements as well as an accurate time signal. The audio frequencies are interrupted precisely on the hour and each five minutes thereafter with a one-minute interval for station announcements.

WAR PROGRAM . . .

Signal Corps Has Wire-Laying Method for All Terrains

A new method of laying communication wire based on a specially designed coil and dispenser enables the Signal Corps to lay its combat wires by airplane, by ground vehicles, or by bazookas and rifle grenades without the use of reels.

The dispenser is about one foot in diameter, one-half foot in length, weighs approximately 25 pounds, and contains about 3,300 feet of assault wire. Communication may be maintained during the laying process, regardless of the mode of transportation employed. Two or more dispensers may be connected in tandem when it is necessary to lay more than one coil of wire without stopping to make a splice.

A container, which has a capacity of eight wire dispensers, has been designed for use by the Army Air Forces so that airplanes can lay a continuous five-mile circuit. Two containers can be mounted on an airplane, one under each wing, to balance the airplane and to lay two circuits at once.

The method has demonstrated its versatility under test with rifle grenades, bazookas, man pack, various ground and amphibious vehicles, and a liason-type airplane which paid out wire at speeds as high as 110 miles an hour. Its adaptability is expected to reduce the requirements for wire-laying equipment and eliminate maintenance of certain mechanical parts.

An important advantage of the new method, which some experts predict may revolutionize the installation of wire communications, is the fact that wire can be laid manually by mountain, ski, or ground troops. Another advantage is silent operation, an important factor in many theaters. The laying of wire by airplane over mountain peaks, deep valleys, or dense forests will simplify greatly the operations of communications troops. In forests or thick jungles wire can be laid over the tops of trees or inaccessible undergrowth. One of the principal uses of paying out wire by bazooka or rifle grenade will be to connect advance patrols or strong points in no man's land.

Allies in Italy Centralize Power-Generation Facilities

The electric generating plants in central Italy have been brought under a central control system under the guidance and direction of the Public Works and Utilities Subcommission of the Allied Commission. This action had the support of the Italian Government and of the private concerns involved.

Assurance of continuous power for military operations was the main consideration behind the move which established a setup patterned after the grid system in force in England for the last 15 years and once proposed for the Tennessee Valley Administration.

Power failures have been prevalent in Italy from either mechanical weakness or other causes reflecting the fact that the plants were patched together with many parts from many regions. These stoppages often brought the work of military establishments to a halt, despite the fact that next door or across the street operations powered by other companies were uninterrupted. It also was found that some areas with a low military urgency had surplus power, whereas others with high military priorities had insufficient power. Adoption of the central control system has effected an equitable distribution of all available power.

Conversion encountered many difficulties among which was the differing frequencies and voltages used by the various companies. A uniform frequency of 45 cycles has been established, and, although the expected variations have occurred, conformity with it now is generally maintained.

The new scheme has been a boon to many small but essential industries, which have been able to produce only at reduced capacity as the bulk of the power in the areas in which they are located was taken by military establishments and large essential industries.

Cargo Ships Use Packaged Power

Walsh-Kaiser photo

Turbine-electric-propelled ships of the Navy's *AKA*-21 combat cargo transport class are fitted with a packaged power plant which is lowered into the hull complete. The unit contains a turbine, generator, and condenser. Even the lubricating oil system, pumps, and piping are included. The small bulk of the turbine generator is made possible by its speed of 4,800 rpm

Bell System Facilities Devoted to War Effort

With extension of telephone service seriously hampered by shortages of central-office equipment, outside lines, and telephone instruments, one of the most consistent expansions occurred near military establishments, according to the annual report of the American Telephone and Telegraph Company for 1944. During the year special attention was given to service men returning from overseas, and particular emphasis was placed on meeting the needs of wounded and convalescent patients in Army and Navy hospitals. At many hospitals, portable bedside service is provided, and attended public telephone centers are equipped with such special features as booths large enough to accommodate a wheel chair or bed, amplifying equipment for the hard-of-hearing, and chest transmitters and head receivers for patients unable to hold the usual type of telephone.

Through longer experience in handling wartime traffic and greater skill in using available facilities, the average time required to complete long-distance calls was reduced in 1944 to 3.2 minutes from 3.7 minutes in 1943. This reduction reversed the trend of the three previous years. The proportion of toll and long-distance calls completed while the calling party remained at the telephone was increased to 85 per cent from 82 per cent in 1943, Bell System reports. The number of toll and long-distance calls rose 8.3 per cent above 1943, and the number of long-distance conversations handled by the long-lines department was 18 per cent more than in 1943. The total was almost as many as the department handled in the combined years, 1938, 1939, and 1940.

During the year overseas radiotelephone service was extended to the island of Trinidad, and further reductions in rates were made for service to the Caribbean area and most of the countries in Central and South America. A start was made on a second transcontinental cable, which will follow a southern route from New York through Atlanta and Dallas to Los Angeles. Telephone facilities along the Pacific Coast and on routes connecting with the East were reinforced to assure meeting military needs of the war with Japan. Among the additions were considerable dial and manual local-exchange equipment, 600 additional toll circuits (principally between the larger cities), and toll switchboards.

Bell Telephone Laboratories divided its year's war work with 55 per cent for the Army, 35 per cent for the Navy, and about ten per cent for the Office of Scientific Research and Development. Special recognition for the Laboratories School for War Training came in a decision of the Navy to assign at least one officer graduate of the school to every major combat ship. Nearly 4,000 Army, Navy, and Marine Corps personnel have been trained in the school, where instruction books and maintenance manuals also are prepared.

An electric antiaircraft-gun director devised by the Laboratories and adopted as standard by both British and American armies was instrumental in lessening the robot-bomb menace in England in the past year.

The report merely mentions the most probable lines which postwar research will take, since peacetime research has been abandoned for the duration. Wartime progress in very short radio waves indicates further experimentation in that direction. The communication possibilities of microwaves will be tested on a radio relay system between New York and Boston for which the Bell System has obtained experimental licenses. Intermediate relay sites have been secured and, as soon as the war permits, construction will be started. Television transmission also may be feasible by this method, the report states.

The Western Electric Company has raised the percentage of its total sales going to the United States Government from 83 per cent in 1943 to 85 per cent in 1944. Sales to the Bell Telephone Companies, though higher than in 1943, were limited to repair and maintenance equipment, new facilities authorized on a priority basis, and the limited number of telephone instruments made for civilian use in the last quarter of the year. At the end of the year the company was producing war equipment, not only at its three main factories, but also in 22 satellite plants leased in 15 cities. In many of its distributing houses, repair-shop facilities were pressed into service for war production. War equipment produced by the company in the last five years includes 5,000,000 military telephones, of which 1,250,000 were head sets for aviators and tank crew men; more than 1,000,000 airplane radio transmitters and receivers; 3,750,000 miles of telephone wire in cables; over 50,000 teletypewriters; and a vast quantity of switchboard, radar, gun-director, and secret combat equipment.

British Employ Underground Cable for 132-Kv Installation

A trial underground cable to carry current at 132 kv recently was installed on the system of the Central Electricity Board in Yorkshire, England, where the variations of load impose a particularly stringent test.

The history of the new compression-type cable dates from about 13 years ago. It was developed to eliminate cable breakdown from ionization made possible at high pressure by the formation of voids in the insulation as a result of the expansion and contraction of the cable under load cycles.

As a remedy the lead sheath of the cable was subjected to an external gas pressure which forces the lead sheath back to its normal position when the temperature of the cable falls, thus preventing the formation of voids. In the early designs the cable was drawn into a continuous pipe of welded steel, filled with nitrogen gas under pressure. In more recent forms the cables are complete in themselves. The usual lead sheath is reinforced and surrounded with another reinforced sheath, and the space between the sheaths is filled with high-pressure gas. Not only is this a more compact and convenient arrangement, but also it has the advantage of excluding all gas from the insulation itself.

The first commercial installation of the early pipe-drawn design was made in London 12 years ago, when a 66-kv link was laid between two power stations in a congested area where overhead lines were not practicable.

Bell System Statistics

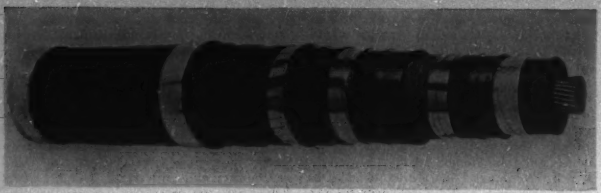
	December 31, 1925	December 31, 1930	December 31, 1935	December 31, 1940	December 31, 1944	Increase During 1944
Number of telephones **	11,909,578	15,187,296	13,573,025	17,483,981	21,580,345	333,716
Number of central offices	6,147	6,639	6,896	7,052	7,342	31
Miles of pole lines	394,529	428,212	407,454	399,838	414,418	2,137
Miles of wire:						
In underground cable	27,769,000	45,116,000	47,639,000	54,339,000	59,918,000	597,000
In aerial cable	12,835,000	23,777,000	26,425,000	30,307,000	33,357,000	246,000
Open wire	4,339,000	5,231,600	4,562,000	4,660,000	4,953,000	15,000
Total	44,943,000	74,124,000	78,626,000	89,306,000	98,228,000	858,000
Average daily telephone conversations* ‡	50,141,000	64,034,000	60,290,000	79,303,000	86,059,000	(98,000)†
Total plant	$2,566,809,000	$4,028,836,000	$4,187,790,000	$4,747,674,000	$5,512,395,000	$124,605,000
Operating revenues*	$ 737,560,000	$1,075,228,000	$ 919,116,000	$1,174,322,000	$1,769,705,000	$121,628,000
Taxes*	$ 58,113,000	$ 84,732,000	$ 94,507,000	$ 184,770,000	$ 417,468,000	$ 44,532,000
Number of employees ‖	292,902	318,119	241,169	275,317	337,863	(5,117)†
Number of American Telephone and Telegraph Company stockholders	362,179	567,694	657,465	630,902	668,013	16,302

† Decrease. * For year ending December 31.

** Excludes private line telephones numbering 96,704 on December 31, 1944. Including telephones of about 6,100 connecting companies and more than 60,000 directly and indirectly connecting rural or farmer lines and systems, the total number of telephones in the United States which can be interconnected is approximately 26,800,000.

‡ For the year 1944 there were approximately 81,826,000 average daily local conversations and 4,233,000 toll and long distance conversations, a decrease of 0.5 per cent and an increase of 8.2 per cent, respectively, over the year 1943.

‖ In addition the Western Electric Company and the Bell Telephone Laboratories had 101,869 employees on December 31, 1944.



Telescopic sample of the 132-kv compression cable made by the Enfield Cable Works, Ltd., London, England

In 1941 a self-contained cable, again at 66 kv, was introduced and design commenced on cables of the same type capable of transmission at 132 kv, which is the voltage adopted by the Central Electricity Board for its main transmission lines.

This cable, which is now on trial, has three separate cores laid round a field, and the conductor in each core has a current-carrying capacity of 324 amperes. The insulation is composed of layers of impregnated paper finished with metallized paper, and the whole is encased in a thin lead sheath reinforced with two copper tapes. Oval construction has been adopted in order to facilitate the free expansion and contraction of the cable. The gas-retaining lead sheath which surrounds the inner sheath is circular in section and is reinforced with two brass tapes lapped over oiled paper as well as with narrow longitudinal tapes. Two layers of nonfibrous insulating material (impervious to water and to dilute acids and alkalies), reinforced with cotton tapes and finished with impregnated hessian, complete the cable, which has an over-all diameter of about eight centimeters.

The cable is terminated in stabilized bushings of a novel type. These contain oil at a pressure equal to that of the gas in the cable and are fitted with a compensator (consisting of a bellows, filled with oil and surrounded with gas, connected to the intersheath space) which automatically balances the pressures of the oil and the gas. Gas is supplied to the cable from gas cylinders through a pressure-control valve, and a relief valve is provided to release any excess of pressure due to a rise in cable temperature. The tests applied to the cable in the factory were of the usual type, including a d-c test at 264 kv and an a-c test at 105 kv, both being for 15 minutes.

The success of the cable is expected to have a marked influence upon the design of future networks for the transmission of electricity in bulk.

Westinghouse Magazine in Portuguese. Westinghouse Electric and Manufacturing Company will issue a bimonthly Portuguese technical magazine, *O Engenheiro Westinghouse*, scheduled to start publication April 1, in addition to its Spanish magazine, *El Ingeniero Westinghouse*, already in existence. Like the Spanish magazine, the new Portuguese publication, will be made up of translations of articles from recent issues of the *Westinghouse Engineer*, plus additional information of special interest to technical readers in Brazil and other Portuguese-speaking countries.

Award Program Announced for Design Textbooks

A $20,000 award program, intended to encourage the preparation and publication of textbooks, one on machine design and another on structural design for fabrication by all processes, including welding, has been announced by The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

Manuscripts may be submitted by any person in the teaching profession, industry, or in private consultation, and may be a revision of an existing textbook. There are three awards in each class; a first prize of $5,000, a second prize of $3,000, and a third prize of $2,000. Among the factors upon which the awards will be based are the educational value and utility of the proposed book, adequacy of coverage, and completeness and thoroughness of treatment consistent with proper length for collegiate use. The award program closes May 15, 1946. Further details may be obtained from the secretary of the Foundation, Cleveland 1, Ohio.

Biddle Company Has 50th Anniversary. With the publication of a brochure entitled "Report at Mid-Century," the James G. Biddle Company, Philadelphia, Pa., announces the celebration of its 50th year in the electrical instrument business. The entire career of the firm has been under the direction of James G. Biddle (A '96), founder of the business. "Report at Mid-Century" presents an informal discussion of Mr. Biddle's professional achievements since the inception of the organization on February 22, 1895.

HONORS

Dugald C. Jackson Celebrates 80th Birthday

On the occasion of the 80th anniversary of his birth, Dugald C. Jackson (F '12), professor emeritus of electrical engineering, the Massachusetts Institute of Technology, and past president of the AIEE, was guest of honor at a birthday banquet held on February 13, 1945, at the Engineers Club, Boston, Mass. Karl T. Compton (F '31), president, the Massachusetts Institute of Technology, presided, and speakers included A. Pen-Tung Sah (M '36), president, National University of Amoy, China; Harold L. Hazen (F '43), head of the department of electrical engineering, Edward L. Moreland (F '21), dean of engineering, and Carlton E. Tucker (F '39), executive officer, department of electrical engineering, all of the Massachusetts Institute of Technology; and Joseph W. Barker (F '30), dean, Columbia University, New York, N. Y.

In addition to the tributes to his ability and accomplishments offered by these present, Professor Jackson received 174 letters of greeting and appreciation from various societies, friends, and former students, which were presented to him in a volume bound in tooled leather. He also was presented with a set of the Encyclopaedia Britannica on behalf of the engineering firm of Jackson and Moreland.

All arrangements for the banquet were made by Mr. Tucker.

JOINT ACTIVITIES

Schenectady Engineering Council Completes History of Growth

With the printing of its constitution, the Schenectady Engineering Council completes a series of articles in the Schenectady Engineering Council *Bulletin* outlining the history of the growth of the council and describing its aims and activities. The council is a continuation of the old co-ordinating committee of AIEE, the American Society of Mechanical Engineers, the American Welding Society, and the New York State Society of Professional Engineers, which has functioned since 1936. Because its objectives and membership have been broadened to include the interests of the community, as well as all technical and scientific persons, it has been felt important to publish this series in order to acquaint the societies, their members, and the community in general with the new organization.

The Schenectady Engineering Council supports the functions of its member societies which overlap the many branches of engineering and science. On a voluntary basis, the societies each organize one general meeting at which they are hosts to all the societies. Five societies are participating this year. Previous issues of the *Bulletin* have presented a combined program calendar for the year including the programs of all member societies, a directory of officers and committee chairmen of the council and of member societies, and a statement of finances including last year's expenses, the budget for this year, and expected net cost. This is the first year under the new council with over-all self-supporting management.

Reading List Issued by ECPD for Junior Engineers

A revised "Reading List for Junior Engineers," reprinted in a convenient form from the 12th annual ECPD report, has been issued by the junior committee on Professional Training of the Engineers' Council for Professional Development. The list is a revision of the original 1936 list and covers natural science; philosophy, including religion;

economics and sociology; psychology; business and industrial management; literature, including poetry, essays, and fiction; history; biography; travel; and the fine arts.

The reading list accents study in the cultural and intellectual fields outside of the specific profession and so eliminates textbooks and encyclopedic works, as well as current "best sellers." In the latter instance, five modern books will appear each year on a mimeographed addenda to the printed listing. After five years on the addenda, the book will be transferred to the master reading list or eliminated.

Copies of the "Reading List for Junior Engineers" are ten cents each (five cents in lots of 50 or more) and may be obtained from the Engineers' Council for Professional Development, 29 West 39th Street, New York 18, N. Y.

Simplified Perpetual Calendar Proposed

A Perpetual Calendar which not only will divide the year into precisely 52 weeks but will enable one to compute all future dates without a printed calendar, has been devised by Lieutenant Willard E. Edwards, United States Naval Reserve, and has reached the Congress of the United States as a Concurrent Resolution requesting the President to urge its adoption at the peace conference.

The proposed method would correct the irregularities of the present calendar by setting aside the first day of the year as a day apart from any week or month and thus permitting division of the remaining 364 days into exactly 52 weeks. The result is that the half-years then become equal, the quarters become equal, and the months fall into the regular rhythmical pattern of 30, 30, 31. The first day of the year, New Year's Day, would therefore be celebrated as a day in itself between December 31 and the second day of the year, Monday, January 1.

The same solution is employed for the extra day in leap year by designating the day following Sunday, June 31, as Leap Year Day so that the year may be divided into two equal parts of 183 days each. Under this arrangement, the first month of each quarter always begins on Monday, the second month on Wednesday, and the third on Friday; and holidays and anniversaries will always fall on the same day of the week as well as the same day of the month. In addition, Monday on the Perpetual Calendar becomes the first day of the week and Sunday the last.

Under the Edwards plan, three three-day holiday periods would occur during the year, Christmas, New Years Day, and Easter, with an additional three-day holiday during Leap Year. Monday, April 15, would be celebrated as Easter Day, a universal legal holiday following Easter Sunday, April 14, which provides the third holiday weekend of the year. Lieutenant Edwards also has suggested that Monday, February 13, be celebrated as "Presidents Day," a nation-wide legal holiday in memory of all past Presidents

THE EDWARDS PERPETUAL CALENDAR

• NEW YEAR'S DAY (a day apart from any week or month) is the first day of each year, a holiday, followed by the 364-day fixed calendar shown below:

JANUARY						
M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

FEBRUARY						
M	T	W	T	F	S	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

MARCH						
M	T	W	T	F	S	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

APRIL						
M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

MAY						
M	T	W	T	F	S	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

JUNE						
M	T	W	T	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

• LEAP-YEAR DAY (a second day apart) is observed only in leap years between June 31 and July 1 as the first day of the second half-year, a holiday.

JULY						
M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

AUGUST						
M	T	W	T	F	S	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

SEPTEMBER						
M	T	W	T	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

OCTOBER						
M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

NOVEMBER						
M	T	W	T	F	S	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

DECEMBER						
M	T	W	T	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

• Those two YEAR-DAYS are definitely named and have a definite purpose. When considered apart from any week, they allow the calendar to become fixed and perpetual.

A Proposal for a New, Up-to-Date Calendar

OTHER SOCIETIES

Resistance-Welding Prize-Paper Contest Announced

Four prizes amounting to $1,000 for resistance-welding technical papers are being offered by the Resistance Welder Manufacturers Association, Philadelphia, Pa.

The first prize of $500 will be awarded for the best paper from an industrial source, consulting engineer, government laboratory, or the like, in which the subject matter is concerned with design for resistance welding. Two $200 prizes will be awarded for papers offering the greatest contribution to the advancement and use of resistance welding, one to an instructor, student, or research fellow at a recognized university, and the other to an industrial contributor. A fourth prize of $100 will be awarded to the author of the best remaining paper in any of the three groups. The contest closes July 31, 1945, and the awards will be announced at the October annual meeting of the American Welding Society. Further particulars may be obtained from Harold S. Card, educational director, Resistance Welder Manufacturers Association, Cleveland 14, Ohio.

Chairmen Named for Building Campaign. W. R. G. Baker (M '41) vice-president, General Electric Company, Bridgeport, Conn., has been named head of the initial gifts committee for the Institute of Radio Engineers campaign to raise $500,000 for a headquarters building in New York City. Powel Crosley, Jr., president, Crosley Corporation, Cincinnati, Ohio, has been appointed honorary campaign chairman.

RESEARCH

Laboratory to Be Established for Precision Measurements

An initial grant of $15,000 has been made to the Illinois Institute of Technology by the Ohmite Manufacturing Company for the establishment of a laboratory for precision measurement of electrical and magnetic quantities, according to Henry T. Heald, president of the university.

The laboratory's goal is to provide precision electrical measurements for the Chicago area approaching in accuracy those of the Bureau of Standards in Washington, D. C. Industries in the vicinity will have the opportunity to use the laboratory's facilities. The laboratory will be located in the engineering building of the Armour Research Foundation of the institute and will be under the direction of E. H. Schulz (A '37) supervisor of electrical-engineering laboratories, and L. W. Matsch (M '41) supervisor of electrical engineering in the foundation.

Chemical Encyclopedia to Be Published in English

Set up as a five-year project, the Encyclopedia of Chemical Technology, now in preparation in this country, will be designed specifically for use in the Americas, according to announcement by the coeditors, Raymond

E. Kirk, head of the department of chemistry and dean of the graduate school, and Donald F. Othmer, professor of chemical engineering and head of the department, Polytechnic Institute of Brooklyn.

To sponsor the project, a new corporation, the Interscience Encyclopedia, Inc., has been established by Interscience Publishers. According to Doctor Kirk, no encyclopedia of chemical technology in the English language exists; the only equivalent to the proposed work at present available is a German encyclopedia. It is proposed that the new encyclopedia will be a 10- or 12-volume set, and the first volume is scheduled to appear in April 1946.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

The Engineer and His Future

To the Editor:

The proposal to form a professional society to promote the interests of all engineers has been given an impetus by the article in the January 1945 issue of *Electrical Engineering* by AIEE President Powel (pages 14–16). This proposal, it seems to me, should be given very serious consideration by members of all the engineering societies. The needs for some such organization are so obvious that they hardly need to be mentioned; however, the nature of the organization to be formed and the policies that it is to pursue call for the fullest discussion and the exercise of greatest discretion. The matter is so complex and the implications so far reaching, that we may be compelled to bring our whole economic setup under scrutiny before a satisfactory program can be formulated.

Under the present organization of business and industry, the engineer stands in a peculiar relationship to his employer. In one sense the engineers, or at least the majority of them, have the same relationships to their employers as do members of the Congress of Industrial Organizations or the American Federation of Labor; that is to say they are hired to render certain services to their employer and are paid a definite wage as agreed upon. In another sense, however, the engineers as a group stand with the owners and managers of industry and against the employee groups that are found in the AFL and CIO. This conflict of interest appears when an engineer in the normal pursuit of his profession installs a more efficient machine or works out a labor-saving process for his employer. If a laborer be eliminated or even if only the grade of skill required be lowered by the innovations made by the engineer, the labor unions will oppose these changes.

The engineer will have to decide against his profession or else take a stand against his union. Whether the labor union attitude is just or reasonable does not matter. As long as the present management-labor relations are maintained, these conflicting interests will persist. If the engineers choose to join a labor union, they will find themselves in a conflict where loyalty is bound to waiver. As an alternative, they can form their own professional organization. This is not a matter of "dodging the issue" but is only a frank recognition of the fact that engineers stand in a unique relationship to both management and labor. This relationship is not paralleled by the bar association, the medical association or by the membership of any other professional society. The engineers will have to set up their own organization and formulate its policies. This organization must not be patterned too closely after any now in existence but must be suited to the needs of the engineering group and to the public welfare.

With this organization strongly established and winning acceptance, the engineers will be in a much better position to attack those problems of industry and of labor that merit their attention. For them to attempt to throw their support to any labor organization as now constituted would be to invite disaster. There are too many who would see the conflicting situation into which they would be thrown and so would not join, or if they did join would be half hearted in their support of it. The inferiority of numbers and the lack of enthusiasm for some of the labor-union activities would so submerge the group that joined as to make their efforts useless. An organization exclusively for engineers seems essential.

G. H. SECHRIST (A'20)

(Staff member, radiation laboratory, Massachusetts Institute of Technology, Cambridge, Mass.)

Proposed Canons of Ethics for Engineers

To the Editor:

Permit me respectfully to submit some comments relating to the "Proposed Canons of Ethics for Engineers" published in a recent issue of *Electrical Engineering* (*Dec '44, p 442*).

It is difficult to understand why a separate code of ethics is needed for any specific group of people; why general ethics, the Ten Commandments, the Golden Rule, and so forth, are not enough ethics for anyone. It is particularly difficult to understand why engineers need a special code of ethics.

Engineers are notoriously more ethical than most people, not by nature but by training and necessity. Engineers are trained to disciplined thinking, and disciplined thinking, which is logical thinking, is bound to result in ethical thinking, because ethical thinking is synonymous with logical thinking. Engineers are of necessity ethical, because a mistake made by an engineer can be traced to him from his own records even after he is dead.

There is a considerable difference between lawyers and doctors on one hand, and engineers on the other hand. Lawyers and doctors are independent individuals, the majority of engineers are doomed to be employees, and it may be a better idea to have a code of ethics for those who employ engineers than one for engineers. There is a particular difference between the lawyer and the engineer as regards ethics. The basic idea of the lawyer is to *prove* something. The basic idea of the engineer is to *find* something. When there is a dispute between two people, the lawyer takes the case of the one who comes to him first and has to try to prove that he is right. The engineer generally has to find out *what* is right, no matter who his client is. So, basically the engineer is forced to be ethical whether he likes it or not. However, I see no harm in having a code of ethics for engineers, and most of the clauses, platitudinous as they may be, will probably cause no harm.

The only possible objection that could be raised is against the provision that an engineer should not criticize the engineering done by another engineer. Why not? When I see that an engineer recommended that my friend build something which is not sound, perhaps even hazardous, why can't I tell my friend, if I don't collect any fee from him or even if I do? Why can't I criticize some nonsensical engineering in a piece of public works? Can't I even criticize a piece of engineering described in the engineering literature? Why not? Are some incompetent engineers, by any chance, afraid of criticism? Any engineer should be glad to expose any engineering to public criticism. It will help him in his future work. Will it be unethical for an engineer to debunk cranks, nuts, quacks, fakers, and the like? But most important of all, if we do have a code, let us do something to kill the two snakes which have been the curse of the engineering profession:

1. The vicious habit of some engineers of collecting a fee or a salary for doing an engineering job and then permitting manufacturers' representatives to do the engineering for them gratis.

2. The vicious habit of some engineering companies of permitting a few engineers to swivel in their chairs without any responsibility while the draftsmen do all the engineering. This practice goes even further. They advise an engineer who applies for a job that there is no opening in the engineering office, but that there is an opening in the drafting room. They hire him as draftsman at low pay, put him in the drafting room, and make him do all the engineering. I even have heard some executives brag about how smart they are to do just that.

Why not do something about these two offenses in the code, if we are to have a code?

M. M. SAMUELS (F '24)

(Chief, technical standards division, Rural Electrification Administration, St. Louis, Mo.)

The Engineering Degree

To the Editor:

The letters in *Electrical Engineering* of Harold M. Gould (*July '44, p 278*) and Carl G. Jones (*Sept. '44, p 352*) concerning engineering degrees are of considerable interest to me since they are illustrative of the desire

of a large number of practicing engineers to obtain an advanced degree. The accomplishments of many of these engineers in research, theory, and design are at least equal to and in many cases more advanced than the work for which the master's and even the doctor's degrees usually are awarded. As is well known, a degree is a title conferred by a school, college, or university as a mark of proficiency in scholarship. Degrees originated sometime in the 13th century and undoubtedly resulted from the practice of mechanics' corporations in which the apprentice, after serving his time, received a testimonial of his skill. In modern times, so far as the writer is aware, the prerogative of granting degrees in the United States has always been confined to educational institutions and has not been assumed by other organizations, even though they be professional or scholarly in their objectives. In the United States the right to grant degrees is conferred on the educational institution by the state legislatures.

In Mr. Jones's opinion there is a widespread granting of degrees with such low requirements that the scientific profession is being cheapened. I believe, however, that the tendency is distinctly in the opposite direction. It is true that engineering degrees have been granted for work of standards and now are considered low and also that at the present time there is considerable variation in the requirements for the same degree. However, during the past few years there has been a distinct raising of engineering school standards and of the requirements for the degrees. This may be attributed to several causes. The art of engineering, particularly electrical engineering, has advanced tremendously in the past few years, because of the availability of such new scientific developments, as electronics, high frequencies, X-rays, and new materials. These new developments have compelled engineering schools to raise the standards of the scientific content of their courses in order that their graduates may meet the increasing demands of the art. Also, standards have been stimulated by educational meetings and conferences, such as those sponsored by the Society for the Promotion of Engineering Education, the Engineers Council for Professional Development, and the technical societies where representatives of industry as well as educators have presented their views on what engineering education should be. In addition, the accrediting program under ECPD in many cases has raised educational standards as well as the physical equipment of engineering laboratories.

Hence, I believe it may be said that at the present time, although perfection in standards for the degree among engineering schools has not by any means been reached, yet the tendency is toward strengthening the requirements rather than cheapening them, as is stated by Mr. Jones. Also, to me, the plan advocated by Mr. Jones, whereby the professional societies assume control of the granting of higher degrees, seems impracticable. As has been stated above, the granting of degrees is a long-established right of educational institutions and is controlled by the state legislatures, and neither is likely to surrender this prerogative. Also, I feel that Mr. Jones's scoring table in some respects is quite unfair. For example, only one point is allowed for the college master's degree and two points for the college doctor's degree. In most cases these degrees represent respectively five years or more, and seven years or more, of "sweat and blood," yet the points awarded are equivalent to a single patent, or a scientific paper, the values of which are sometimes doubtful. A single patent or a scientific paper indicates, usually, a knowledge of a specific subject, whereas an advanced degree necessitates a thorough knowledge in a wide field.

Mr. Gould suggests that schools should shorten the vacations so that a master's degree may be obtained in four years. Off hand, this suggestion appears to have merits, but experience with accelerated wartime programs has shown that most students cannot maintain high scholastic levels under the steady strain of a sustained program. Also, with accelerated programs several educational values are lost, such as time for reflection and absorption, time for participation in many desirable extra-curricular activities, and opportunities for industrial experience, all of which unquestionably add to the breadth and full development of the student. Several of the students in wartime training leave the institutions saying that they want to come back and "really absorb" the material which has been covered. Also, it is necessary for a large number of the students to work during the summer vacations in order to meet part of their college expenses. Hence, as desirable as it may appear to operate educational plants on a 12-month basis, nearly all are planning to revert to the two-term academic year after the needs of the war and of the returning veterans have been met. With graduate students, however, most engineering schools do permit work in the summer vacation in order to expedite the work toward the degree.

Mr. Gould also suggests that advanced degrees be obtained by correspondence courses. There is no doubt that such courses, if pursued faithfully, would be highly beneficial and would meet the educational needs of numbers who have no other access to advanced study. The objection to granting advanced degrees for such work is that a degree connotes much more than the mastery of the content of courses. There are several intangible values, such as contacts with the teachers and their influence on the student and his ways of thinking, the use of libraries, contacts with other students, and acquaintance with the customs and traditions of the institution. Also, the work for advanced engineering degrees should involve laboratory and research work, which are not readily accomplished from a distance.

To me, however, it seems that both of these letters express a more or less widespread and innate desire on the part of many engineers in industry who are ambitious and whose scholastic attainments and contributions to the art should receive recognition by advanced degrees and that avenues should be made available for obtaining such degrees. Engineering schools already have made some attempts to meet the situation. In a few industrial centers evening courses and cooperative courses sponsored by industries and engineering schools are available for graduate study. However, it is doubtful if demand will permit the extension of this practice beyond a relatively few industrial centers. Also, the committee on professional training of ECPD sponsors postgraduate training of students in industry, although means for awarding degrees are not always available in those programs. In the matter of difficulty of returning to school for an advanced degree, the "year of graduate study" to which Mr. Gould refers means an academic year consisting usually of only eight months. Hence, it is sometimes possible for a practicing engineer to arrange a part-time leave of absence in order to obtain an advanced degree. In the work for the doctor's degree a large proportion of the time is required by the thesis. Many schools now permit a large part of the research and preparation of the thesis to be done outside. Hence, efforts are being made to meet the situation, but, nevertheless, there are still wide opportunities for industry and the engineering schools to co-operate more closely so as to make available more avenues by which practicing engineers may obtain recognition for professional accomplishments.

In my opinion there would be greater satisfaction among many practicing engineers who feel that their attainments are worthy of an advanced degree, if they obtained at least the master's degree before entering industry. Many of the leading engineering educators agree that now it is practically impossible in a four-year program to prepare students to meet the existing advanced developments in science and technology. In the "Report of the (SPEE) Committee on Aims and Scope of Engineering Curricula"[1] it is stated:

> "Preparation for the higher technical levels of engineering . . . clearly requires more than a four-year period and should extend beyond the baccalaureate degree."

The engineering schools are making every effort to encourage students of scientific ability to remain for graduate work. Financial aids are being extended by the granting of liberal scholarships, fellowships, and part-time teaching and research assignments, so that nearly any able and ambitious student now can continue his graduate studies, irrespective of his financial status.

The greatest handicap to graduate study is industry itself. The personnel representatives visit the schools and make alluring financial offers to undergraduates, particularly to those who have outstanding ability and, hence, who are best adapted to remain for graduate work. These students are advised that further engineering training will be provided by the industry, that the student will be paid while learning, and that further degrees are not important. With such temptations it is difficult to persuade students to continue academic study and undoubtedly many of them later will be in the category of those for whom Mr. Jones and Mr. Gould are speaking. They have shown that they are highly qualified for a higher degree but that no avenue for obtaining it will be readily available to them.

Mr. Jones and Mr. Gould have, I believe, performed a service in calling attention to an existing deficiency in postgraduate engineering education, and I am certain that all engineering educators are in sympathy with any operative plan that will remedy the situation and at the same time will not jeopardize in any way the ideals of scholarship for which the degrees are symbols.

REFERENCES

1. Report of the Committee on Aims and Scope of Engineering Curricula. The Society for the Promotion of Engineering Education *Journal of Engineering Education*, volume 30, March 1940, page 555.

2. Report of Engineering Education After the War. The Society for the Promotion of Engineering Educa-

tion *Journal of Engineering Education*, volume 34, May 1944, page 589.

CHESTER L. DAWES (F'35)

(Associate professor of electrical engineering, graduate school of engineering, Harvard University, Cambridge, Mass.)

NEW BOOKS

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Radio's 100 Men of Science. By O. E. Dunlap. Harper and Brothers, New York, N. Y., and London, England, 1944. 294 pages, illustrated, 8¾ by 5¼ inches, cloth, $3.50. (ESL.)

The brief biographies in this readable book cover a wide field. The first section is devoted to pioneers of electricity, from Thales of Miletus to Mahlon Loomis. The second section traces developments in radio and electronics from Hughes's invention of the microphone to the present day. The sketches are gobd and are in many cases based on personal acquaintance. Nearly one half of the men are living. Portraits of almost all of them are included.

Alignment Charts. By M. Kraitchik. D. Van Nostrand Company, New York, N. Y., 1944. 94 pages, illustrated, 9¼ by 6 inches, cloth, $2.50. (ESL.)

The opening section of this book provides a review of the algebra, analytic geometry, and determinants necessary for an understanding of the methods of chart construction. The representation of various equations then is discussed and illustrated by means of exercises. Applications are made to the fields of chemistry, engineering, manufacturing, and investments. Some of the charts given are ready for use.

Peace, Plenty, and Petroleum. By B. T. Brooks. Jacques Cattell Press, Lancaster, Pa. 1944. 197 pages, illustrated, 7¾ by 5¼ inches, cloth, $2.50. (ESL.)

After a brief historical survey of the American petroleum industry, the author devotes several chapters to the importance of petroleum in our industrial economy with particular reference to war needs. Petroleum substitutes are discussed, and the geographical distribution and political implications of petroleum deposits are thoroughly covered. The author emphasizes the steady decrease in new producing areas in the United States and discusses the problems arising in connection with the increase in our need for foreign oil.

Rocket Research. By C. P. Lent. Pen-Ink Publishing Company, New York, N. Y., 1944. 102 pages, illustrated, 9¼ by 6 inches, stiff cardboard, $5. (ESL.)

The early history and present status of the development of rocket and jet propulsion are well presented in this small volume. The author covers both theory and practical application, including descriptive material on the various types of weapons brought out by the war. The text is illustrated by more than 100 photographs and diagrams, and some 150 American and British patents are listed.

Treatise on the Mathematical Theory of Elasticity. By A. E. H. Love. Fourth edition. Dover Publications, New York, N. Y., 1944. 643 pages, illustrated, 9⅛ by 6 inches, cloth, $3.95. (ESL.)

This standard widely known treatise has been out of print for some time, and this republication will be welcomed by many engineers and physicists. It is an American reproduction of the latest English edition, complete in every respect, with the advantage of a greatly reduced price.

Solvents. By T. H. Durrans. Fifth edition. D. Van Nostrand Company, New York, N. Y., 1944. 202 pages, illustrated 8¾ by 5¼ inches, cloth, $6. (ESL.)

The first part of this book deals with scientific fundamentals: solvent action, solvent power, plasticizing solvents, solvent balance, viscosity, vapor pressure and evaporation rates, inflammability, and toxicity. The second part deals comprehensively with individual solvents, mainly with a view of facilitating intelligent use of them in the cellulose-lacquer industry. A table of solubilities and a dictionary of trade names are appended.

Metals and Alloys Dictionary. By M. Merlub-Sobel. Chemical Publishing Company, Brooklyn, N. Y., 1944. 238 pages, 8¾ by 5⅛ inches, cloth, $4.50. (ESL.)

Over 10,000 useful metallurgical terms are contained in this reference volume: definitions of metallurgical terms; compositions, properties, and uses of all important commercial alloys; physical constants and properties of the chemical elements; brief descriptions of machinery and processes used in modern metallurgy; and others. Many trade names are included.

Prodigal Genius, the Life of Nikola Tesla. By J. J. O'Neill. Ives Washburn, New York, N. Y., 1944. 326 pages, illustrated, 8¾ by 5¼ inches, cloth, $3.75. (ESL.)

This book is concerned chiefly with Tesla's talent as an inventor. It describes not only his discoveries within the field of electricity but also his work in other fields. Giving full credit to his status as a brilliant engineer, it also portrays the eccentricities which almost equally set him apart from the normal run of human beings. As the book shows, both aspects were in evidence quite early in his life.

Clouds, Weather, and Flight. By T. C. Gillmer and H. E. Nietsch. D. Van Nostrand Company, New York, N. Y., 1944. 161 pages, illustrated, 11¼ by 8⅛ inches, cloth, $3.75. (ESL.)

The contents of this book represent a development of the basic physical laws of the atmosphere into the principles of air-mass analysis and forecasting. Part I covers this material generally for the layman. Part II considers the application of the study of meteorological conditions to aviation, with a special chapter on weather hazards. Part III discusses gliding and soaring flight. The book is illustrated copiously and has a glossary of meteorological terms.

Aerodynamics. By L. R. Parkinson. Macmillan Company, New York, N. Y., 1944. 112 pages, illustrated, 8½ by 5½ inches, cloth, $2.25. (ESL.)

This introductory work presents briefly both elementary and advanced phases of the science of flight. Beginning with the theoretical consideration of atmospheric properties and air flow over surfaces, the author continues with practical discussion of lift and drag, stability, and airplane performance. The final chapter explains the construction and use of wind tunnels.

Galvanómetros y Oscilógrafos, Volume 1—Galvanometros. By S. Gerszonowicz. La Facultad de Ingenieria, University of Montevideo, Montevideo, Uruguay, 1943. Obtainable through G. E. Stechert and Company, New York 3, N. Y., and Editorial Médico-Quirúrgica, Buenos Aires, Argentina, 391 pages, illustrated, 10 by 7 inches, paper, $6. (ESL.)

This book is a very detailed and encyclopedic discussion of galvanometers, especially from the viewpoint of the user. Their theories, construction, and performance are considered at length. Moving-magnet, moving-coil, and string galvanometers; electrodynamometers; induction instruments; and moving-iron and electrothermic instruments are discussed. A final chapter tabulates the data on current instruments found in the catalogs of 15 American and European manufacturers. Each chapter has a bibliography.

Treatise on the Analytical Dynamics of Particles and Rigid Bodies. By E. T. Whittaker. Fourth edition, Dover Publications, New York, N. Y., 1944. 456 pages, illustrated, 9⅛ by 6 inches, fabrikoid, $3.50. (ESL.)

This work long has been considered one of the best on its subject and has enjoyed wide use as a textbook and as a reference book for mathematicians and physicists. The present publication reproduces the fourth edition, which appeared in 1937, at a reduced price.

PAMPHLETS

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Sound Films for Classroom Use. Bulletin 583. **Motion and Time Study Films.** Bulletin 582. State University of Iowa, Iowa City. 7 pages.

Postwar Planning for Metropolitan Utilities. John Bauer. National Municipal League, 299 Broadway, New York 7, N. Y., 31 pages, 35 cents per copy, four for $1, ten for $2.

NAM Survey of Employment and Reconversion. National Association of Manufacturers, 14 West 49th Street, New York 20, N. Y., 17 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Dynamic Measurements on Electromagnetic Devices

E. L. NORTON
NONMEMBER AIEE

FOR the investigation of relays and similar electromagnetic apparatus, data giving the variation of current and flux as well as the motion of the armature during the operating cycle are of great value. The rapid-record oscillograph[1] has been used extensively for current measurements and, where a moderate accuracy is sufficient, is very satisfactory. Data on the flux also may be obtained by graphical integration of oscillographic data, but such a process is laborious and, unless great care is taken, is of doubtful accuracy. The development of a shadowgraph attachment[2] for the oscillograph provided a means of measuring armature motion at the same time and with the same order of accuracy as the current measurements.

The method to be described has been developed to take current-time, flux-time, displacement-time, and velocity-time data by point by point readings on a d-c microammeter. By careful design and operation of the apparatus, it is possible to measure current and flux with an accuracy determined chiefly by that of the ammeter which in the better-grade instruments is $\pm^1/_2$ per cent of full scale. The accuracy of displacement and velocity measurements, which depend upon the use of a photoelectric cell and amplifier, is not as good but is still sufficient for most work and is probably better than other methods of comparable simplicity and ease of operation, such, for example, as high-speed motion pictures or the shadowgraph method.

Although intended primarily for dynamic measurements, the apparatus also provides a rapid, accurate, and sensitive method for obtaining other magnetic data, such as the magnetization curve, where the variation with time is not of interest. It is not suitable for measurements involving extremely slow changes in magnetism, but for apparatus similar to that used in the telephone plant, where such changes usually take place within a half second or less, it is entirely satisfactory.

Paper 45-65, recommended by the AIEE committee on instruments and measurements for presentation at the AIEE winter technical meeting, New York, N. Y., January 22-26, 1945. Manuscript submitted November 16, 1944; made available for printing December 26, 1944.

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Measurement of Flux With a Search Coil

The principle upon which all of the measurements are based may be understood from an explanation of the measurement of flux by the use of a search coil.

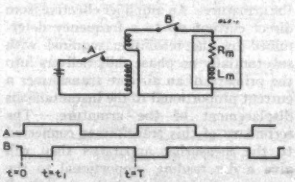


Figure 1. Circuit for the measurement of flux by a search coil

As in Figure 1, the relay or other structure is connected to the supply voltage through a contact known as the A contact. A search coil is connected to a d-c instrument through the B contact. Contact A is opened and closed with about 50 per cent make and break at such a rate that the flux in the relay has sufficient time to reach a substantially steady state during both the closed and the open intervals. Contact B operates in synchronism with contact A. It always opens just before the A contact closes at which point the flux has dropped to its minimum point, or substantially the residual value. The point of closure of the B contact may be adjusted to occur at any time during the cycle.

Let the flux linking the search coil of N turns at any time be Φ. The resistance of the search coil and wiring is R_s. Assume that the ammeter has a resistance R_m and inductance L_m the current flowing is then given by

$$N\frac{d\Phi}{dt}+L_m\frac{di}{dt}+(R_m+R_s)i=0 \qquad (1)$$

The instrument will read the average value of current for the cycle. Let the period of the cycle be T and let the time of closing the B contact be t_1, measured from the time of the previous open period. The direct current read by the instrument will then be

$$I_0=\frac{1}{T}\int_{t_1}^{T} i\,dt$$
$$=-\frac{1}{(R_m+R_s)T}\int_{t_1}^{T}\frac{d}{dt}(N\Phi+L_m i)\,dt$$
$$=\frac{(N\Phi+L_m i)_{t_1}-(N\Phi+L_m i)_T}{(R_m+R_s)T} \qquad (2)$$

Now the product $L_m i$ at t_1, when the B circuit is closed, must be zero. Furthermore, if the period T is long in comparison with the time of decay of the flux Φ and with the time constant L/R of the measuring circuit, the product $L_m i$ is also negligible at $t=T$. We may write then

$$\Phi_{t_1}-\Phi_T=\frac{RTI_0}{N}\times 10^8 \qquad (3)$$

where R is now the total resistance of the measuring circuit. The factor 10^8 has been added to reduce the units to the common ones. The flux ΦT is the residual flux so that, if this is taken as a reference value, the value of the flux at the time of closing the B contact is simply

$$\Phi=\frac{RTI_0}{N}\times 10^8 \qquad (4)$$

There are available relatively rugged commercial instruments of the pivot type with 10-ohms resistance and a full-scale reading of 0.2×10^{-3} amperes. If then $T=0.1$, a full-scale deflection would be obtained for a value of $\Phi=2{,}000$ with a ten-turn search coil of negligible resistance. If more sensitive instruments of the suspension type be used or a lower value of T, the sensitivity may be increased still further. With commercial instruments and $T=0.1$ second, the method is being used for measurements with a sensitivity approximately 100 times as great as that of a fluxmeter of comparable ruggedness.

It may be objected that the flux in equation 1 is made up not only of the flux to be measured but also of a component due to the current in the measuring circuit. This is true, and the flux

threading the search coil is different during the time the B contact is closed from what it would be without this circuit. Note, however, that we are not concerned with how the flux varies between times t_1 and T but only with its value at the limits. Since the flux at t_1 is that which has been established with the search-coil circuit open, the one requirement is that the constants be such that the current in the measuring circuit be substantially zero at the time T.

Measurement of Current

The instantaneous value of current is measured by connecting the primary of an air-core transformer in series with the circuit and connecting the secondary in place of the search coil. Under these conditions the instantaneous current at time t_1 is given by

$$i=\frac{RT}{M}I_0 \qquad (5)$$

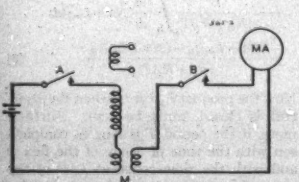


Figure 2. Circuit for the measurement of current

where M is the mutual inductance of the air-core coil and the other symbols have the same significance as before. The circuit is shown in Figure 2.

Measurement of Flux Using Bridge Circuit

In many cases, it is desired to measure the flux linkages in the magnetizing winding itself, either because the use of a search coil is inconvenient or because the data are desirable for other reasons. For such purposes, the circuit in Figure 3 is used. The relay or other device to be measured together with the primary of an air-core inductance, if current readings are also desired, is made one arm of a bridge which is balanced to direct current by closing both the A and B contacts and adjusting R_d for no deflection of the meter. If the contacts then are operated with the period T, the instrument will read a current I_0, and the flux turns of the relay at time t_1 will be

$$N\Phi\times10^8=R_mI_0T\times\left[1+K\left(1+\frac{R_o}{R_m}+\frac{R_d}{R_m}\right)\right]-L_1i \qquad (6)$$

where $N\Phi$ is the flux linkage of the winding, or N the number of turns and Φ the average flux per turn (the other quantities being indicated on the drawing). The term L_1i is a correction term, usually negligible, involving the self-inductance L_1 of the primary of the air-core coil and i the instantaneous current at time t_1; i is determined by a separate measurement as previously described. If its value be not needed, the air-core coil is omitted from the circuit.

If the bridge circuit be used to measure the flux during the decay part of the cycle, after A has opened, a slight error is introduced because of the presence of the shunt $(1+K)R_o$ across the circuit. To avoid this, the connections are modified for measurements on decay to that shown in Figure 4. When this circuit is used, B is never closed until A has opened. The resistance $K(R_o+R_m)$ is placed in series with the meter to make the expression for flux linkages the same as before.

Measurements have been made using the bridge method on apparatus having a flux of from less than one maxwell to over 50,000 maxwells and taking currents of from a fraction of a milliampere to over an ampere.

Measurement of Displacement and Velocity

An optical system is arranged such that the illumination falling on a photoelectric cell is proportional to the displacement of the armature. An amplifier effective from direct current up to a frequency determined by the resolution required with substantially no phase shift delivers into the primary of an air-core transformer a current proportional to the instantaneous displacement of the armature. The secondary of this transformer connected to the measuring apparatus then will give a d-c reading proportional to the armature displacement at the time the B contact closes.

If the amplifier be changed to one in which the output current is proportional to the rate of change of input voltage, or, in other words, to one in which the voltage gain is proportional to the frequency with a 90-degree phase shift, the instrument then will read a value proportional to the rate of change of displacement or to the instantaneous velocity. Under these conditions, the amplifier differentiates the input voltage once, the output transformer differentiates the second time, and the d-c instrument integrates once, leaving a net result of one differentiation.

Apparatus

Figure 5 shows the instrument designed to take the measurements described. In the center is the flux machine. It consists of a small synchronous motor with a gear-shift mechanism allowing a choice of five accurately held pulse rates varying

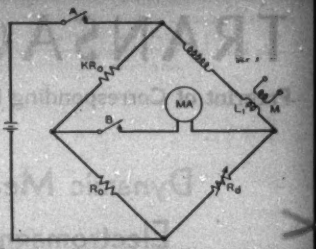


Figure 3. Bridge circuit for the measurement of flux linkages in a relay winding

from one to ten a second, the A and the B contacts with provision for accurately setting the time t_1 to any part of the cycle, a built-in bridge with the choice of a wide range of ratio arms, and a set of keys by which any of a number of test circuits may be quickly set up.

In addition to applying an on-and-off battery condition, the instrument is designed to supply battery reversals to the apparatus under test. This is used in testing core materials to eliminate residual effects and for polar relays and similar structures.

The method used to control the time of closure of the B or meter circuit is adapted from the usual form of pulse machine.[3] As in Figure 6 two contacts are provided, each closed for 50 per cent of the cycle. One is fixed in phase and is set to open just before the A or battery circuit is closed. The second contact may be adjusted in phase through 360 degrees and may be connected either in parallel or series with the first. When the two contacts are exactly out of phase and in parallel, the circuit is closed at all times as illustrated in position 1. If the second contact now be shifted in phase to position 2, the contacts still being in parallel, the circuit will be closed for three-fourths of the time, and, if shifted to position 3, for half the time. The contacts then are connected in series. In position 4, the circuit still is closed for half the time. A further shift to position 5 gives closure for one-fourth of the cycle, and, finally, in position 6 a shift of 360 degrees from

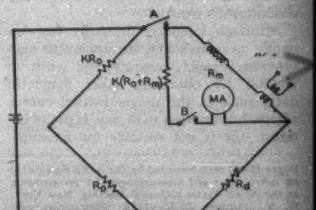


Figure 4. Modification of Figure 3 used to measure decay of flux

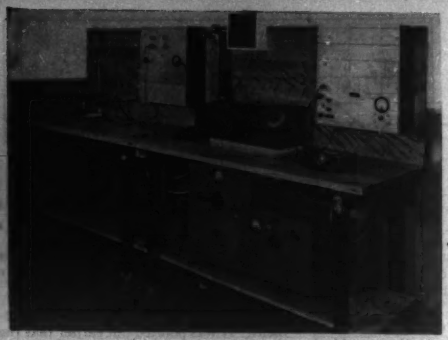


Figure 5. Apparatus assembled for use

the start gives no closure. Note that in all conditions the circuit is opened by the fixed contact, which maintains a fixed phase relation with the A contact and is closed by the movable contact.

In practice, it is more convenient to supply two movable contacts 180 degrees apart in phase, one for the parallel connection and one for the series, and to shift their phase through only 180 degrees. The ordinary pulse machine uses only a single movable contact and 180 degrees shift but has not the feature of opening the circuit at a fixed phase.

In the instrument shown, the B contacts are bronze brushes bearing on silver segments on a seven-inch disk. The conducting segments cover half of the circumference so that one contact per revolution is made. The movable brushes are adjusted by a worm-drive dial of the type used for precision condensers, one division corresponding to 1/1,000 of a cycle. The A or battery circuit is opened and closed by relatively heavy cam-driven platinum-iridium contacts with provision for ease of cleaning and adjustment.

The gear-shifting mechanism consists of two shafts each carrying five gears, the first shaft geared to the motor, the second to the commutator disk. Between the shafts is a carriage carrying five idler gears, which is raised and lowered by a rack and pinion from a knob on the front of the apparatus. For each revolution of the knob, the successive idler gears are brought into mesh with the successive pairs of gears on the two shafts allowing a choice of five speeds to be obtained.

The elements of the bridge circuit of Figure 3 are built into the instrument. The resistances are held accurately and are of ample current-carrying capacity. The value of R_e is 250 ohms, the decade resistance R_d has a maximum resistance of 111 ohms with an 0.2-ohm rheostat for accurate balance, and the value of K may be selected from five values from 1 to 120. Provision is made to connect an external resistance in place of R_d, if the decade boxes have insufficient range or current-carrying capacity. For a typical 1,000-ohm relay, a value of $K=40$ would be used so that the circuit constants would be: $R_e=250$, $KR_e=10{,}000$, $R_d=25$. A

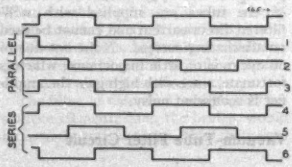
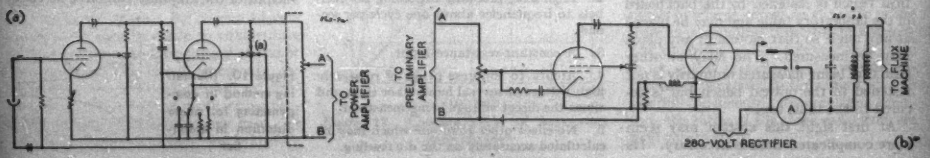


Figure 6. The operation of the B contact

pulse rate of $T=0.25$ ordinarily would be used.

For the measurement of current, three large toroidal air-core mutual inductances are provided, having mutual inductances of 0.02, 0.10, and 0.50 henry. These make it possible to measure currents of from less than one milliampere to several amperes. The coils are selected by means of a three-position key and a plug provided to short-circuit the primary, if current measurements are not required.

Figure 7. The amplifier for displacement and velocity measurements



Apparatus for Displacement and Velocity Measurements

The optical system and amplifier used for the measurement of displacement and velocity are shown at the left of Figure 5.

Preliminary experiments indicated that the type of amplifier required for displacement measurements, that is one with uniform gain and substantially no phase shift extending down to direct current, presented no serious difficulties because of the relatively low net gain required and the relatively high output voltage of the photoelectric cell. The amplifier for velocity measurements, however, where the voltage gain was required to increase linearly with frequency presented more practical difficulties. The indicated maximum gain required was well over 100 decibels at a frequency of 1,000 or 2,000 cycles, and, moreover, the phase characteristic required was one which increased the difficulties of avoiding self-oscillation.

From many theoretical and practical considerations it was decided to make the amplifier in two sections, each with feed-back and each with two stages. The first or preliminary amplifier is shown in Figure 7a.

This is a two-stage feed-back amplifier, but the feedback may be either a capacitance for velocity measurements or a resistance for displacement measurements. The capacitances are of mica and the resistances of a precision type, and the gain is sufficient so that the net gain is substantially independent of everything but the feed-back impedance over the range of interest. This permits absolute measurement of displacement and velocity to be made, if a single constant which is ordinarily the total motion of the armature is known. The contacts of a small relay operated from the heater circuit are placed at a to avoid the drain on the plate battery, if the feed-back switch is left on a resistance terminal.

For measuring displacement the switch is placed on one of the six resistance contacts and for measuring velocity on one of the four capacitance contacts. The successive values of capacitance and resistance change in the ratio of three, or three and one third, to one so that a wide range of gain is obtainable. The circuit is operated at as high a feedback as is consistent with the required sensitivity. Finer adjustment of the gain may be made by the potentiometer on the right which is a part of the second or power amplifier shown in Figure 7b. This is also a two-

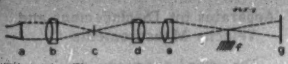
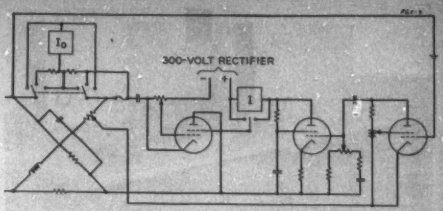


Figure 8. The optical system for displacement and velocity measurements

a—Lamp
b—Condensing lens
c—Slit
d, e—Objectives
f—Moving vane
g—Photoelectric cell

Figure 9. The filter circuit to smooth the data to the measuring instrument



stage feed-back amplifier with a resistance feedback modified by the network shown to compensate for the distributed capacitance of the air-core output transformer.

The first three stages of the amplifier are high-gain pentodes and the output a power pentode. The first tube is mounted in the same container which holds the photoelectric cell, which is shielded electrostatically and magnetically except for a small window by a permalloy shell. The lamp is a nine-volt, two-ampere bulb, which is operated normally at five to six volts, a range of 2–12 volts being available by a rheostat.

The Optical System

Most of the features of the optical system are due to the advice and assistance of associates who have been connected with the sound-motion-picture development. The fundamental design is similar to the film-reproducing system with certain necessary changes in dimensions.[4]

In Figure 8, *a* is the lamp, *b* the condensing lens, *c* a slit, *d* and *e* objective lenses, *f* a vane on the part whose motion is to be studied, or the sharp edge of the part itself, and *g* is the photoelectric cell. The lamp and the condensing lens are the same as those used in the film reproducer. The slit is the same except that its width has been increased to 0.005 inch and a feature added permitting its length to be adjusted from zero to about 0.10 inch. The objective lenses are inexpensive Bausch and Lomb achromatic lenses. Lens *e* is interchangeable for different focal lengths and may be moved back and forth in the supporting tube for precisely focusing the image of the slit on the moving part.

The three lenses and slit are mounted in a tube fastened to the lamp housing, which in turn is fastened to a short optical bench which also supports the photoelectric-cell container. The lamp housing contains provision for bringing the lamp filament to the proper position. The optical bench is fastened to the backboard of the laboratory table and may be placed at any angle so that motion in any plane may be measured. The relay or other structure being measured ordinarily is not fastened to the optical bench but is secured to the table top.

At first sight this system may seem more complicated than is necessary. Its advantage is that it provides a rectangular beam of light of constant width and adjustable length at the point to be measured. The necessity for numerous light shields and screens is done away with, although it is advisable to throw a black cloth over the whole apparatus, when once adjusted, to keep out the overhead illumination.

The reason for this last is of interest. The flux machine is driven by a synchronous motor on the same 60-cycle mains as the overhead lights, so that the contacts on the machine operate in synchronism with the fluctuations in light intensity. Any measurements made with overhead illumination getting into the cell will, therefore, have a superimposed 120-cycle ripple. For the same reason extreme care had to be taken to avoid any 60-cycle pickup in the apparatus. The heaters of the tubes are supplied with well-filtered direct current and cannot be used on alternating current. Noise not due to 60 cycles is of little importance, which is fortunate, since with high gain the amplifier is somewhat noisy.

Vacuum-Tube Filter Circuit

It has been assumed tacitly in the foregoing theory that it is possible to read the direct component of a complex wave simply by placing a d-c instrument in the circuit. This is true if a sluggish instrument is used with a relatively high pulse rate. Many measurements, however, require a slow pulse rate, and the more convenient rapid-reading types of instruments will follow the pulses to such an extent that an accurate reading is impossible.

On the right of the photograph is the apparatus which serves as a very efficient low-pass filter. This filter must fulfill a variety of very stringent requirements, chief of which may be listed:

1. Low loss to direct current.
2. High loss, probably exceeding 30 decibels to frequencies above one cycle per second.
3. A constant-resistance input.
4. Ability to suppress peaks of relatively high voltage of several hundred or thousand times the direct voltage being measured.
5. No effect other than one which may be calculated accurately on the d-c reading.
6. The circuit should not increase greatly the time required for the instrument to reach a steady reading.

Requirement 3 may call for some comment. It was pointed out earlier that the method requires the time constant of the measuring circuit to be small in comparison with the period of the pulses. A filter built in the ordinary way to have high suppression to pulses of period T would not have a time constant small in comparison with this figure. The requirement of constant-resistance input is a convenient way of expressing the necessity of fulfilling this condition.

The original work on the system used was done by R. F. Wick, and many of the features to be described are attributed to him. The circuit diagram is shown in Figure 9. From left to right the elements are as follows: a balanced impedance bridge containing the ammeter in one arm, a blocking capacitor, a vacuum tube used as a plate-supply impedance for the power tube, and a two-stage amplifier with an interstage phase-adjusting circuit. The three-point double-pole key when in the normal position removes the meter (50 ohms) and substitutes a 50-ohm resistance. When off normal the meter is connected in either polarity.

The operation of the circuit is best understood by assuming the reactance elements to be omitted from the bridge and the contact on the potentiometer forming one diagonal to be at the lower left. The input to the amplifier is then directly across the line, and any feedback is eliminated, since the bridge is balanced. Any alternating component applied will be amplified and sent back through the meter in the opposite polarity from that coming directly from the line. If then the gain in the amplifier is correct and its phase shift nearly zero, the alternating component through the meter will be greatly reduced.

The bridge provides the constant-resistance feature at the input, since the output of the amplifier can have no effect

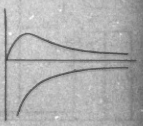


Figure 10. Illustrating method of compensating for phase distortion in amplifier

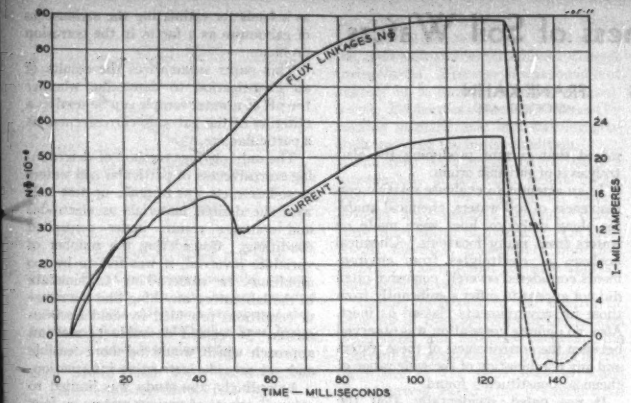


Figure 11. Current and flux variation in central-office-type relay

Dashed lines—Decay with resistance
Capacitor protective circuit

on the input impedance. It does however necessitate a loss from both line and amplifier to the measuring instrument.

Practically, the difficulty in design is in securing an amplifier with enough peak-output capacity and negligible phase shift at frequencies from one cycle up. This has been accomplished by a combination of several methods. Most of the phase shift is introduced by the plate capacitor in the last stage. The effect of this is reduced by using as a plate-supply resistance to the 6*L*6 used as a power stage, a second 6*L*6 operated with a plate potential of about 50 volts and a screen of 300 volts. The equivalent resistance in so far as voltage drop is concerned is about 1,600 ohms, but the resistance to fluctuations in the plate current is many times this figure.

The gain of the amplifier is controlled by feedback secured by the potentiometer in the diagonal arm of the bridge. The gain is sufficient so that a substantial amount of feedback may be used with a consequent further reduction in phase shift.

The final phase compensation is secured by the interstage potentiometer. The effect of this is illustrated in Figure 10. The lower curve is the net phase shift of the amplifier without the interstage circuit. The upper curve is the phase shift, which may be introduced before the grid of the second stage. By proper adjustment these may be made to compensate each other down to a frequency of one or two cycles. The circuit constants are such that the final adjustment of low-frequency phase may be made with a negligible effect on high-frequency gain. It may be of interest that, if the bridge be unbalanced by short-circuiting the lower 50-ohm resistance, an error of 20 per cent or more is introduced in the d-c reading because of the extremely large effective reactance of the feed-back amplifier. If the bridge be unbalanced by short-circuiting the meter, the amplifier is quite likely to motor-boat and blow the fuse used to protect the meter. It is for this reason that the meter key is made to replace the meter by a 50-ohm resistance. When in this position, the fuse also is short-circuited to avoid needlessly blowing fuses with the high surges which frequently occur when the amplifier is turned on and the capacitors start to charge.

The filter, as described, omitting the reactance elements from the bridge, would be entirely satisfactory within the power

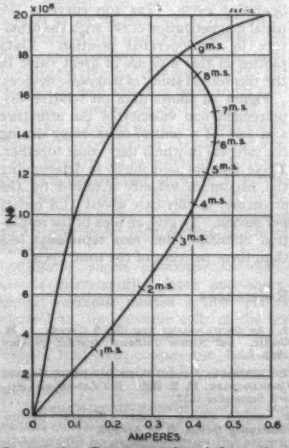


Figure 12. Operate cycle of heavy-duty electromagnet

capacity of the amplifier. With certain measurements, notably those of velocity, the peaks of the wave as applied to the filter, which in this case would be proportional to acceleration, are so high that no reasonable amplifier would be able to follow them. These knifelike peaks, however, are so sharp that they may be removed easily by reactance elements added to the bridge as shown. It will be noted that the bridge is still of constant resistance and still is balanced at all frequencies.

Three adjustments are provided on the amplifier, one controls the feedback, a second the phase correction, and the third the plate current. A plate milliammeter is provided to measure either plate current or the sum of plate and screen currents, as will be clear from the diagram. The amount of suppression is controlled by a three-position key, which may be used to cut down the sizes of the capacitors in the circuit in a ratio of two and four to one. In cases where one of

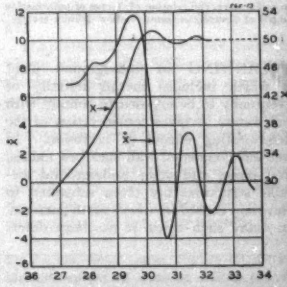


Figure 13. Relative motion of armature and core of relay at the end of its stroke when striking stop pins

x—In mils
ẋ—In inches per second
Abscissas—Time in milliseconds after closing contact

the higher pulse rates is used, adequate suppression and somewhat faster readings may be secured by using smaller capacitors. With the maximum suppression, two cycles may be reduced to such an extent that it has no detectable effect on the meter pointer. Accurate measurements at one cycle may be made, although there is a slight motion of the pointer.

Analytical studies have indicated that the transient response of the circuit depends to a large extent on the ratio of the interstage coupling capacitor to the output capacitor and, moreover, that there is an optimum ratio of the phase-compensating capacitor to the other two. In altering the amount of suppression, therefore, the ratios of the three capacitors are held constant.

Galvanic Corrosiveness of Soil Waters

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Synopsis: Results are presented of a study of the relation of pH of soil waters to galvanic action between couples of lead, copper, iron, and carbon. Galvanic-cell tests were made using as electrolytes actual soil waters or soil extracts from 31 locations at which trouble had been experienced. The following conclusions apparently can be drawn from this investigation:

1. Galvanic corrosiveness on lead, copper, and iron appears generally more severe for soil waters of low pH than for those of high pH.

2. Indications are that the static potentials of lead and iron are practically constant in soil electrolytes of pH up to approximately ten; as pH is increased above ten, lead becomes more negative and iron more positive. The potential of copper becomes more negative in substantially straight-line relation with increasing pH. Carbon potentials appear to be practically independent of pH of soil waters.

3. For electrodes of lead, copper, iron, and carbon in soil waters, the relation of degree of polarization to pH of electrolyte seems to show definite trends.

PLANNING an underground plant which includes metals initially or eventually to be exposed to contact with soil waters involves consideration of the deteriorating effects of corrosion. In wet environments, lead-sheathed cables, iron pipes, and other underground metallic structures are often subjected to corrosion caused by direct earth currents. In many such cases, it has been determined that current producing the electrolysis is of galvanic origin.

In an attempt to evaluate relative corrosiveness of soil waters, chemical analyses along orthodox lines were made on waters from many locations. Chemical analyses of electrolytes from environments considered severely corrosive often did not appear to differ significantly from those for environments classed as inert. Also, no definite correlation was observed between the corrosiveness of these waters and any combination of the wide range of chemical constituents found.

It was noted, incidentally, that the hydrogen-ion concentration of the waters varied from approximately pH 2 to pH 12. Also, experimental data in hand indicated a possible relation between galvanic corrosiveness and pH of electrolyte. Because of the ease with which the pH of a water sample can be determined, such a relation could prove of great value as a basis for estimating the seriousness of galvanism as a factor in the corrosion problem.

This paper summarizes the results of an investigation to determine whether the pH of a water sample can be used as a criterion of the galvanic corrosiveness at a particular site.

The only obvious method of determining corrosiveness of particular soil waters or soil extracts was to make up test cells with the desired materials as electrodes and compare results under controlled conditions. Considering the number of variables involved, it was felt to be too ambitious an undertaking to simulate in the laboratory anything like the range of conditions provided by field environments. It seemed desirable to seek an approach which would be more feasible and yet provide instructive information.

Accordingly, the study was limited to galvanic effects of various waters on four materials commonly occurring as electrodes in underground installations. The electrodes selected were lead (from commercial lead sheathing), copper (electrolytic), iron (low-carbon steel), and carbon (arc-lamp electrode or core of a dry cell).

Thirty-one samples of manhole waters, soil waters, and distilled-water extracts from soil specimens, collected from various locations where trouble had been experienced, were used as electrolytes. Several of the waters used were from sources hundreds of miles apart. For comparison, municipally-supplied tap water was also included.

Galvanic-corrosion behavior was investigated by studying the "current versus potential" relations of pairs of the electrodes on the various electrolytes, following the suggestion of Burns.[1] The test cell comprised a beaker containing 200 milliliters of electrolyte with two test electrodes immersed for two and one-half square inches of surface. A saturated calomel electrode was used as a reference electrode, connection being made through a salt bridge. The test and reference electrodes were disposed in a triangle with the opening of the salt bridge ap-

Paper 45-60, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE winter technical meeting, New York, N. Y., January 22-26, 1945. Manuscript submitted November 29, 1944; made available for printing December 27, 1945.

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Measurements

The results of a few typical measurements are given in Figures 11, 12, and 13.

Figure 11 shows the build-up and decay during operation and release of a central-office telephone relay having a number of contact springs. The scalloped effect in the current build-up curve is due to the sudden changes in load on the armature as successive contact springs are picked up. The more rapid build-up of the current at the start of the cycle as compared with the flux is caused by the presence of eddy currents in the core.

Two decay curves are shown, one with a resistance-capacitor protective shunt across the operating contacts and the second with no protection. The voltage tending to produce a spark across the contacts is equal to the slope of the flux curve and this is reduced substantially by the addition of the shunt. The finite rate of decay of flux with no shunt is due to the presence of eddy currents.

Figure 12 shows similar data taken for a heavy-duty laminated-core electromagnet but plotted in a different manner. This is effectively a dynamic magnetization curve of instantaneous flux plotted against instantaneous current during the operating cycle. The top curve is the usual magnetization curve with the armature in the operated position. Data plotted in this way are of great value in the theoretical study of magnetic devices.

Figure 13 shows data on relative displacement and velocity of the armature and core of a central-office relay during the interval in which they come together. These data are used chiefly in determining the maximum velocity attained by the armature, in this case about 11.8 inches per second. To give an idea of the resolution obtained, this plot represents less than three per cent of the total cycle.

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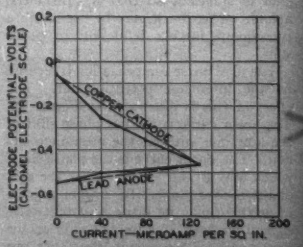


Figure 1. Current-versus-potential characteristic of lead–copper galvanic couple in soil-water electrolyte of pH 7

Dashed lines show polarization slopes

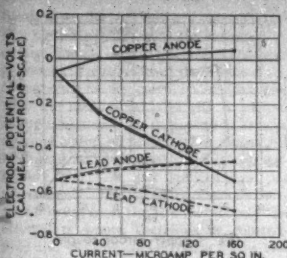


Figure 2. Current-versus-potential characteristics for two cells with current supplied externally; one cell having two copper electrodes and the other cell (broken lines) having two lead electrodes

Light dashed lines show galvanic-couple characteristic reproduced from Figure 1

proximately at half the depth of immersion of the test electrodes. All potentials were measured with a null potentiometer, and short-circuit currents were determined by an ammeter with potential drop compensated with an external voltage source as suggested by Denison.[2] The cell tests were made at an ambient temperature of 75 degrees Fahrenheit ±5 degrees Fahrenheit.

Previous experience having indicated a knowledge of the chemical constituents to be of little help in evaluating corrosiveness, chemical analyses of these waters were not made except for electrometric determination of hydrogen-ion concentrations.

In Figure 1 is shown a typical "current versus potential" characteristic for the lead–copper couple in one of the soil waters. This characteristic shows how the potential differences between each test electrode and the calomel electrode vary with magnitude of current flow between electrodes as the cell is gradually short circuited. The individual curve for each electrode is known as its polarization curve. The dashed straight lines shown in Figure 1 were drawn by connecting the points representing the open-circuit conditions for each electrode and the point representing the short-circuit condition. Each dashed line is a fair approximation of the actual anodic or cathodic polarization curve for the respective electrode and its slope will be referred to as the "polarization slope." It will be observed that anodic polarization slopes will be positive and cathodic polarization slopes, negative.

From preliminary tests, it became apparent that one of the most critical aspects of these test cells was the technique of cleaning the electrodes before each test to give reproducible potentials. Various treatments were tried and it was found simplest to remove a surface layer of metal with nitric acid and wash thoroughly with tap water followed by distilled water. This proved effective except in the case of the carbon electrodes which were difficult to depolarize. However, it was found that heating in a Bunsen flame to approximately 250 degrees Fahrenheit followed by soaking in nitric acid and washing generally restored the initial condition.

The cells were permitted to reach a substantially steady state before taking final readings. On open circuit several minutes were required to reach steady state in a number of instances. On short circuit, however, considerably more time generally was required to reach approximate stabilization.

Another approach to the electrolytic behavior of the electrodes in the various electrolytes was made by observing the "current versus potential" relation of two electrodes of the same material when direct current was supplied to the cell from an outside source. This method produces simultaneously the anodic and cathodic polarization curves for the particular electrode material. In order to determine the galvanic relation of any two materials in the electrolyte, it is not necessary to set up the actual cell. For all practical purposes, the proper curves can be combined to show what galvanic action will result.

Figure 2 illustrates this relation for lead and copper electrodes in the same electrolyte used in the tests shown in Figure 1. A galvanic cell comprised of a lead and a copper electrode in this electrolyte should give the characteristic indicated by the combination of the anodic curve of the lead and the cathodic curve of the copper. This is substantiated by reproducing by light dashed lines in Figure 2 the characteristic for this cell shown in Figure 1.

Figure 3 shows static electrode potentials to the calomel electrode scale for lead, copper, iron, and carbon plotted against pH of the electrolyte. Because of scattering of the points representing the data, envelopes have been drawn to show the general trends. It is seen that the potentials of lead and iron seem to be substantially constant in electrolytes of pH up to ten. As the pH is increased above ten, lead becomes more negative and iron more positive. The potential of copper becomes increasingly negative in practically linear relation with pH as the pH increases. The potential of carbon appears to be practically independent of pH of electrolyte.

Figure 4 shows envelopes for open-circuit electromotive force and short-circuit currents, plotted against pH of electrolyte, for galvanic cells of the six combinations of the electrodes: lead-copper, lead–iron, copper–iron, lead–carbon, copper–carbon, and iron–carbon, respectively.

The electromotive forces shown by the dotted envelopes in Figure 4 are obviously what would be expected from the appropriate combinations of the static electrode potentials shown in Figure 3. Of particular interest is the reversal of polarity of the lead–iron couple in soil waters above approximately pH 10 as shown in Figure 4B.

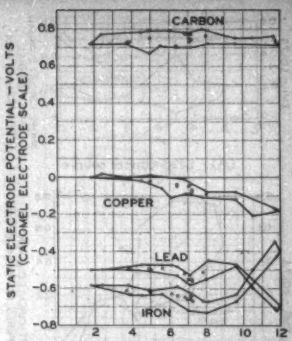


Figure 3. Static electrode potential versus pH of soil-water electrolyte for electrodes of lead, copper, iron, and carbon

The envelope of short-circuit currents versus pH for the lead–copper couple, shown in Figure 4A, does not appear to evidence any characteristic trend. However, the maximum current for this couple (400 microamperes per square inch at pH 5.0) is of the order of half the maxima found for the lead–iron and copper–iron couples. With carbon as one electrode of the couple, current maxima were of the order of 20 to 40 times this magnitude.

The envelope of short-circuit currents for the lead–iron couple, Figure 4B, shows highest values of current below pH 7. Thereafter, as the pH increases, the current diminishes to zero at pH approximately 10 to 11 and then increases gradually with polarity reversed.

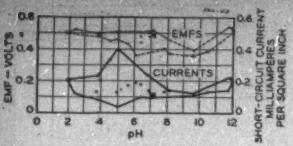
The short-circuit current envelope for the lead–carbon couple, Figure 4D, appears to have a minimum at approximately pH 8, with the highest value of current magnitude at pH 11.7.

The short-circuit currents for copper–iron, copper–carbon, and iron–carbon couples apparently have maximum values below neutral pH (pH 7) tapering down to low values at pH of approximately 12. In the copper–iron couple in particular (Figure 4C) in the soil-water electrolyte of pH 12, the short-circuit current was only 2 microamperes per square inch.

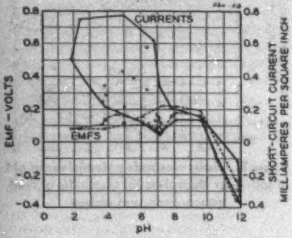
Figure 5 shows slopes of the anodic and cathodic polarization curves versus pH for the lead, carbon, copper, and iron electrodes, respectively.

From Figure 5A it appears that lead is practically nonpolarizing at both extremes of pH with increased polarization occurring between approximately pH 7 to 10.

As shown in Figure 5C, copper as an anode is nonpolarizing at low pH and rises to a peak in the region of pH 12.

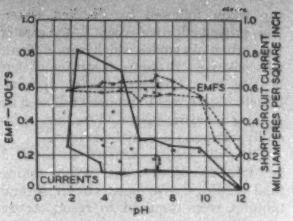


(A). Lead-copper couple

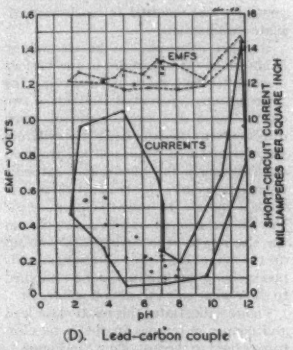


(B). Lead-iron couple

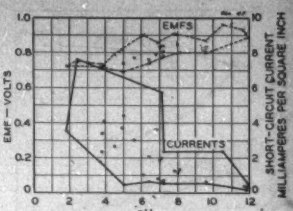
Figure 4. Open-circuit electromotive force and short-circuit current versus pH of soil-water electrolyte for galvanic-couple combinations of lead, copper, iron, and carbon electrodes



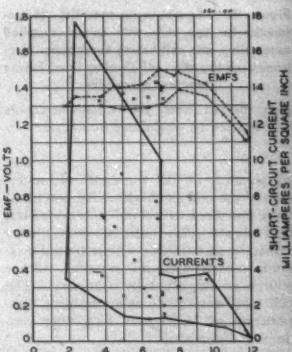
(C). Copper-iron couple



(D). Lead-carbon couple



(E). Copper-carbon couple



(F). Iron-carbon couple

There appears to be considerable scattering of degree of polarization below pH 7 for copper as a cathode, but a pronounced peak of high magnitude was obtained for the soil water of pH 12.

Iron as an anode polarizes little in soil waters of pH less than approximately ten. Above this value, as shown in Figure 5D, polarization is very marked. As a cathode, iron appears to polarize increasingly with increase in pH.

The polarization slopes for carbon, as both anode and cathode, shown in Figure 5B, indicate low values at the extremes of pH with a hump in the region approximately pH 7 to 10. Although carbon may not be of special interest as a galvanic electrode in virgin soils, it often becomes of importance in urban fills. The uniformly high positive potential of carbon will tend to cause severe anodic corrosion of practically any other metallic underground structure when such structure and the carbon are related to their environment as a short-circuited galvanic couple. This is particularly true where the soil waters are at extremes of pH. When voltage measurements between metallic earth substructures show a constant potential difference of the order of one volt, an open-circuited galvanic cell, involving carbon as a cathode, is strongly indicated. Bonding together of such structures is contraindicated.

A test was made to determine the influence of the ohmic resistance of the electrolytes on the results obtained. A galvanic cell of one of the pairs of electrodes in a representative electrolyte was set up as usual and permitted to stabilize for a dynamic condition. Electrode potentials were carefully observed while one of the electrodes was moved about in the beaker. No changes in the dynamic electrode potentials were observed during this test, although the electrode spacing was varied from a separation of approximately two inches to closest proximity possible without actual contact. It was therefore concluded that the ohmic resistance drops in the electrolyte could be neglected. As a matter of interest, the resistivity of the soil waters tested ranged from a few hundred to several thousand ohm-centimeters at 25 degrees centigrade.

It should be thoroughly understood that this study has been confined to galvanic effects on actual soil waters. This means that, for the conclusions drawn, corrosion by direct chemical attack or by microbiological organisms is expressly excepted. Also, it is emphasized that the effects observed in this study were obtained for soil waters which very probably have somewhat related chemical characteristics. In other words, soil waters probably contain many salts in common with the likelihood of similarity of galvanic behavior, despite variations in concentration and acidity. It is not intended to generalize the conclusions drawn beyond soil-water environments.

It is appreciated that underground environments introduce many variables not taken into account here, such as surface films, movement of electrodes, flow of electrolytes, and so forth. The authors did not attempt the comprehensive investigation which would be required to determine the effects of these factors. Although having no counterpart in field occurrences, the cleaning of the electrodes by chemical removal of surface layers eliminated an important cause of variation in results. Conceding that this procedure produces results which are not completely representative of practical effects, it is still believed the data are indicative of the relative order of severity of galvanic corrosion.

The polarization slope is a direct ratio of voltage to current density and can be considered to be a measure of the current density which would result from a given dynamic electrode potential. With known magnitudes of voltages between identified structures in an underground electrolysis circuit, and provided local galvanic effects could be satisfactorily taken into account, it may prove possible to estimate the current-density distribution on the structures concerned.

It may also prove feasible to determine relative severity of corrosion on electrically-interconnected metallic underground structures of different materials. This is illustrated by the following example.

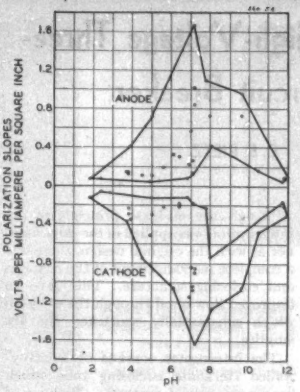
Assume a composite anode of copper and lead in an underground electrolysis circuit energized from a d-c source (for example a lead-cable sheath with copper-

bonding conductors in a wet manhole and at a potential positive to the surrounding environment). Assume also that the local galvanic current between the lead and the copper can be neglected. Consider first that the electrolyte is of pH 8. From Figures 5A and 5C it is observed that the average value of polarization slopes for both lead and copper at pH 8 is approximately 0.8 volt per milliampere per square inch. The densities of anodic current flowing from the two metals into the electrolyte would therefore be comparable and electrolytic corrosion of the two metals would be of similar severity.

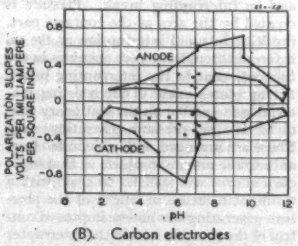
Next, consider conditions the same except the electrolyte to be at pH 12 instead of pH 8. Figures 5A and 5C indicate that at pH 12 the anodic polarization slope for lead is down to approximately 0.1 volt per milliampere per square inch while the anodic polarization slope for copper has increased to the order of two volts per milliampere per square inch.

The significance of this difference in polarization slopes is that to maintain equal dynamic potentials to the environment at pH 12, the current flow from the lead anode must be of the order of 20 times that from the copper. As a consequence, anodic corrosion of the lead component of a composite lead–copper electrode will be many times as severe as for the copper. Preliminary tests appear to corroborate this analysis.

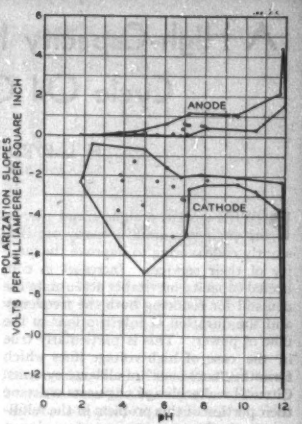
It is hoped that the material which has been presented will stimulate interest to the extent that others may be induced to contribute data to provide a better understanding of this subject.



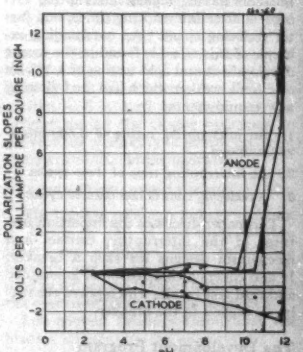
(A). Lead electrodes



(B). Carbon electrodes



(C). Copper electrodes



(D). Iron electrodes

Figure 5. Slopes of anodic and cathodic polarization curves versus pH of soil-water electrolytes for lead, carbon, copper, and iron

Conclusions

Assuming that the waters which were used are representative soil electrolytes, it is believed the following conclusions are indicated by the data presented.

1. Galvanic corrosiveness on lead, copper, and iron appears generally more severe for soil waters of low pH than for soil waters of high pH.

2. The static potentials of these electrodes have the following relationships to pH of soil waters:

(*a*). The static potential of lead is practically constant at about −0.5 volt (calomel electrode scale, e_c) in soil electrolytes of pH up to approximately ten. Above this, lead becomes more negative with increase of pH.

(*b*). As the pH of the soil waters increases, the potential of copper becomes more negative in substantially straight-line relation with pH. It changes in potential from approximately zero volts (e_c) at pH 2, to approximately −0.2 volt (e_c) at pH 12.

(*c*). The potential of iron is substantially constant at approximately −0.6 volt (e_c) in soil waters of pH up to approximately ten. Above this value, iron becomes increasingly more positive with increase of pH.

(*d*). Carbon potential appears to be practically independent of pH of soil waters at approximately +0.75 volt (e_c).

3. The degree of polarization of these electrodes apparently shows the following relationships to pH of soil electrolytes:

(*a*). Lead is practically nonpolarizing at both extremes of pH with a possibility of increased polarization occurring between approximately pH 7 to 10.

(*b*). Copper as an anode is nonpolarizing at low pH and rises to a peak in the region of pH 12. For copper as a cathode there also appears to be a peak of high polarization at pH 12.

(*c*). Iron as an anode polarizes little in soil waters of pH less than ten. Above this value, polarization is very marked. As a cathode, iron appears to polarize increasingly with increase in pH.

(*d*). Carbon appears to be practically nonpolarizing at extremes of pH, with slight polarization occurring in the region approximately pH 7 to 10.

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A High-Capacity High-Voltage Three-Cycle Oil Circuit Breaker

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POWER-system designers and operating engineers quite properly are constantly endeavoring to improve the quality of their services. Increases in connected capacity inevitably accentuate the demand for reducing both the frequency and the duration of interruptions in the flow of power. This is particularly true in the case of high-voltage lines which form the "backbone" of all large systems. Circuit-breaker-design engineers welcome their portion of this problem in the fulfillment of the requirement for circuit breakers having higher interrupting ratings, shorter interrupting times, and faster reclosing times. An outstanding example of this trend is found in the recent development and field testing of a 138-kv oil circuit breaker which had the following new requirements:

1. An interrupting rating of 3,500 megavolt-amperes.
2. An interrupting time of three cycles.
3. A reclosing time of less than 20 cycles.

This paper discusses the important features of the interrupting contact and mechanism designs for such a breaker. It also covers a comparison of laboratory and field test results which prove the ratings assigned to the breaker.

The Development Program

The development of the new breaker involved four major considerations:

1. The type of interrupting contacts.
2. The operating mechanism for the breaker.
3. The breaker-mechanism linkage.
4. Proof that the breaker in its over-all performance would meet the new requirements.

The Interrupting Contacts

Multibreak interrupters for five-cycle breakers were developed some years ago and were subjected to exhaustive field tests at that time.[1,2] These tests and subsequent operating experience have shown the current-interrupting characteristics of these interrupters to be so satisfactory that the new problem evidently was one of further development of this principle rather than one of new fundamental research.

This development resulted in the new multibreak interrupter for three-cycle tank-type breakers as shown in Figure 1. Although the oil-blast principle of arc interruption was applied in the same manner as with the original design, there was a complete rearrangement of the contacts and enclosing structure. This gave an improved flow of oil through the arc path which substantially shortened the arc lengths.

The interrupter consists of a heavy-walled Herkolite enclosing tube which houses two sets of contacts. Each set of contacts comprises a pressure-generating and an interrupting break. Pressure is created by the arcs as the contacts part, resulting in rapid interruption as the oil is forced through the port openings in the tube adjacent to the interrupting break. Arcing plates made of arc-resisting material are mounted on the stationary contacts at the pressure-generating side. These are arranged with a definite clearance to the moving contacts so that high-current arcs will transfer to them with a resultant decrease in length of the pressure-generating arcs and an improved control of the pressure within the interrupter results. Earlier tests demonstrated that more than adequate oil-blast action was always present on higher currents. Therefore, the reduction in the length of the pressure-generating arc does not jeopardize good interrupting performance. Light current-interrupting performance is not compromised since the arc initially starts from the main contact surfaces. The fact that satisfactory oil-blast action is available throughout the interrupting range is clearly demonstrated by the test results which are discussed later.

The enclosing tube is adequately secured to an adapter at the upper end, and it is secured to the support for the moving-contact assembly at the lower end. The stationary contacts are mounted on the tube or bolted to the end supports. The moving contacts are assembled on an insulation rod which forms part of the moving-contact assembly. This assembly can be removed from the bottom of the interrupter without dismantling of the contacts. This permits the complete inspection of all of the contact and insulation parts without changes of adjustment. Corona shields at the top and bottom ends of the interrupter improve the electrostatic-field distribution.

Each interrupter has mounted on it and connected in parallel with the interrupting contacts a resistor for use primarily during the interruption of capacitance current. The resistors limit to safe values overvoltages due to restriking when long transmission lines are deenergized. The effectiveness of these resistors has been fully demonstrated by field tests and operating experience in the last three years.[3] The complete assembly of interrupters, resistors, and moving

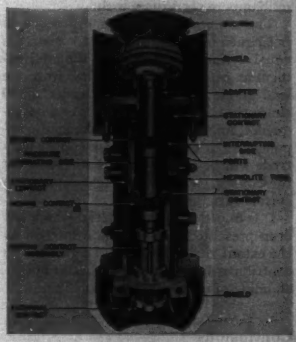


Figure 1. View of a cutaway 138-kv multibreak interrupter

The moving contacts are in the closed position and move downward when the breaker opens. Short-circuit currents are interrupted before the end of their travel

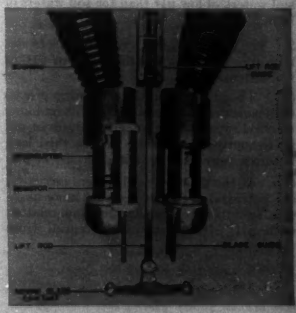


Figure 2. Pole-unit assembly of 138-kv multibreak interrupters showing resistors and lightweight moving-blade contact

Paper 45-45, recommended by the AIEE committee on protective devices for presentation at the AIEE winter technical meeting, New York, N. Y., January 29-Feb. 2, 1945. Manuscript submitted November 28, 1944; made available for printing December 21, 1944.

H. L. Byrd is managing engineer and E. B. Rietz is section engineer of the power-circuit-breaker division, both with General Electric Company, Philadelphia, Pa.

The authors thank the American Gas and Electric Service Corporation and the Ohio Power Company for making the field tests possible and the engineers of these companies for their co-operation during the tests.

Figure 3 (left). The pneumatic operating mechanism for a three-cycle breaker

The unit is self-contained with its own air system and is mounted directly on the first-pole-unit tank

Figure 4. Enlarged view of the high-speed trip on the three-cycle operating mechanism

This reduces the breaker dead time

blade contact for a single-pole unit is shown in Figure 2.

Operating Mechanism for the Breaker

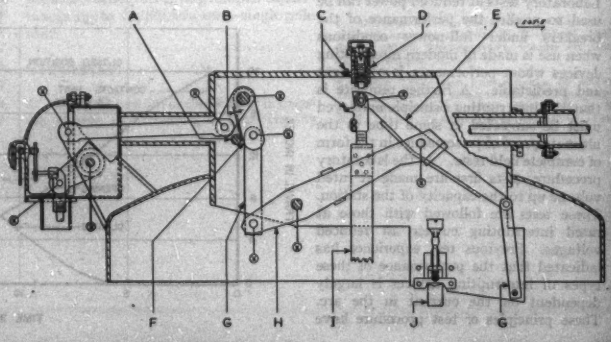
The high-speed opening and reclosing requirements for this breaker necessitated an operating mechanism of the stored-energy type with performance not met by existing designs. High-speed opening could possibly have been obtained by the use of heavy opening springs and large trip currents with existing mechanisms, but this would be conducive to short life and excessive maintenance on both the operating mechanism and the breaker. To attain the required opening speed without encountering these difficulties, a new high-speed trip latch was developed for the pneumatic operating mechanism which already had proved adequate for high-speed reclosing. This mechanism with its simplified linkage, low energy consumption, and satisfactory operating record made it a logical selection.

The operating mechanism is shown in Figure 3. It is of the pneumatically trip-free type. The construction of the power unit, compressed-air system, storage reservoir, and controls is essentially the same as described in a previous paper before the Institute.[4] All of these parts with the exception of the storage reservoir are assembled in a weatherproof housing which is mounted as an integral part on the front-pole-unit tank. The storage reservoir is mounted underneath and attached directly to the housing. For trip-free operations, so that there may be no delay in the opening of the breaker contacts, an auxiliary air connection is made to the top of the cylinder above the piston. This admits air above the piston on such an operation and speeds the reversal of piston motion so that the breaker contacts are free to open as fast as on a normal opening operation. An emergency air connection with suitable shutoff valves permits the use of an auxiliary air supply with a minimum of inconvenience.

Figure 4 shows a close-up view of the high-speed trip latch. This consists of an armature attached directly to the trip shaft and held by a permanent magnet housed in a magnetic frame while the breaker is closed. The mechanism linkage is arranged so that at all times when the breaker is closed there is a positive force tending to pull the armature away from the face of the magnet. The trip impulse is applied to a coil built into the magnetic circuit. Flux from the coil cancels the holding force of the permanent magnet by shifting its flux out of the armature circuit and the armature is released. Therefore, there is a minimum of time between the trip impulse and the start of movement of the breaker. An exciting coil is used to supplement the magnet during the closing operation to prevent the possibility of jarring out from the shock of the closing operation.

Figure 5. Pole-unit linkage of the three-cycle breaker showing relationship of parts, low-friction bearings (X), and provisions for decelerating moving parts at ends of stroke

A—Stop
B—Stop clearance
C—For travel-recorder connector
D—Buffer
E—Lever
F—Crank
G—Link
H—Beam
I—Link rod
J—Dashpot



Breaker Mechanism Linkage

The breaker pole-unit linkage is shown in Figure 5. All of the main fulcrum points are equipped with antifriction bearings and are marked *X*. These are used to reduce the breaker dead time after the operating mechanism is unlatched.

Low-friction bearings throughout the breaker linkage give two advantages:

1. The energy requirement for the operating mechanism is reduced.
2. Greater acceleration at the start of the opening stroke is produced without increasing the velocity during the arcing period.

The reduced friction losses permit the use of lighter opening springs, thus reducing

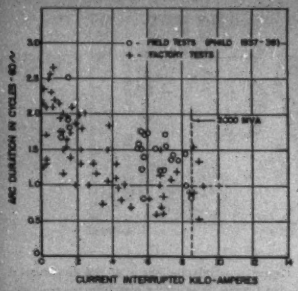


Figure 6. Interrupting performance of original 138-kv multibreak interrupters showing arc duration in cycles at various currents

Field tests made on triple-pole breaker at 138 kv. Factory tests made on a single-pole-breaker unit at voltages of 110, 88, 66, 44, 22, and 14.5 kv

the energy required to charge these springs on closing as well as the energy over the entire closing stroke. This reduces the forces on the linkage parts and permits modifications to reduce the inertia of these parts, thus further accelerating the opening operation.

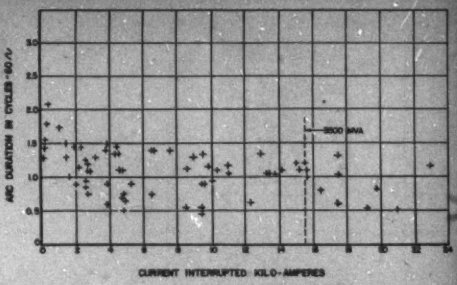
With the conventional toggle arrangement of the linkage to obtain increased mechanical advantage as the contacts engage, the low-friction bearings are of greatest advantage when the toggle is closed. Therefore, they give greater acceleration during the time that the contacts are parting.

Proof of Performance

Performance Demonstrated in Laboratory Tests. It has long been evident that it would be difficult to provide test stations with short-circuit capacities equal to the ever increasing interrupting ratings of high-voltage circuit breakers. This has led to the development of empirical procedures for making tests with reduced power which experience indicates are fully adequate for design purposes. Laboratory tests at reduced power can be used to predict the performance of the breakers under full-power conditions when use is made of modern interrupting devices whose performance is consistent and predictable. A further requisite is that the interrupting principle employed must be subjected at some time to the ultimate proof of performance in the form of complete field tests. In the laboratory procedure, tests first are made at rated voltage up to the capacity of the station. These tests are followed with those at rated interrupting current at reduced voltages. Previous test experience has indicated that the performance of these types of interrupting devices is largely dependent on the current in the arc. These principles of test procedure have been substantiated by years of laboratory-test experience and by field tests. The 1937–38 Philo field tests on multibreak interrupters are a good example.[3] Figure 6 shows the results of those field tests as compared with the laboratory tests. The arc durations are in the same order of magnitude for like currents in both laboratory and field tests.

Figure 7. Interrupting performance of new 138-kv multibreak interrupters during laboratory tests

Tests made on a single interrupter at voltages of 66, 55, 44, 22, and 14.5 kv



A summary of a complete series of laboratory tests made on the new interrupter is represented by Figures 7 and 8. Figure 7 shows interrupting tests made up to currents of 23,000 amperes. The arc durations are well within a limit of 1.5 cycles except on the very low end of the current range. This limit was established in conjunction with a contact parting time of 1.5 cycles for the operating mechanism. The arc durations for different voltages are of the same order of magnitude, illustrating that the interrupter performance is not primarily dependent on applied test voltage. Pressures were measured within the interrupter, and their values were well below the safe working strength of the structure.

Ultrahigh-speed-reclosing tests were made under identical conditions, and the performances on the first and second interruptions are shown by the plotted results in Figure 8. These show equivalent interrupting performances, based on substantially the same arc durations, and demonstrate that the interrupter always is left with a sufficient quantity of oil for adequate interruption on the second operation for such short reclosing times as 20 cycles or less.

Figure 9 shows the no-load operating tests on a triple-pole breaker including opening, closing, reclosing, and trip-free

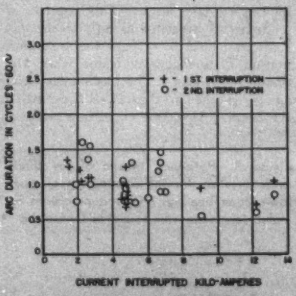
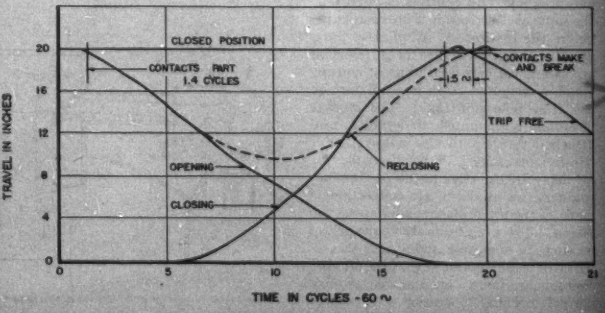


Figure 8. Interrupting performance of new 138-kv multibreak interrupters during laboratory tests on high-speed reclosing, showing comparative performance of first and second interruptions of the duty cycle

Tests made on a single interrupter at voltages of 66, 55, 22, and 14.5 kv

Figure 9. Time-travel curves of the three-cycle 20-cycle-reclosing breaker showing opening, closing, reclosing, and trip-free operations under no-load conditions



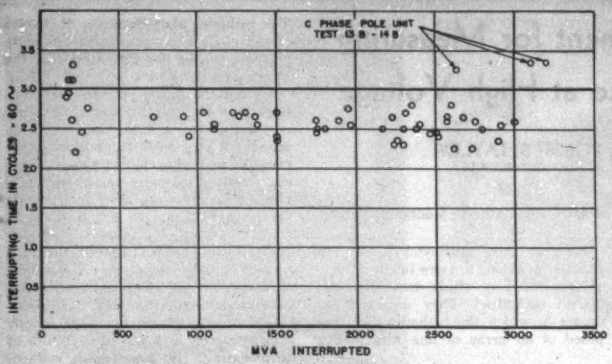


Figure 10. Interrupting performance of three-cycle breaker on field tests showing breaker interrupting times at various duties

operations. A contact parting time of 1.4 cycles was obtained. The reclosing time of less than 20 cycles indicated an operating mechanism with adequate power to perform under load conditions.

Performance Demonstrated in Field Tests. The final proof of performance was demonstrated during two series of field tests that were made at the Philo station of the Ohio Power Company on the weekends of July 22 and August 5, 1944. This represented the largest concentration of power ever made available for full-scale circuit-breaker testing. A full description of the test setup and test results is contained in a paper presented at the 1945 winter meeting by Philip Sporn and Harry P. St. Clair entitled "Field Tests and Performance of Heavy-Duty High-Speed 138-Kv Circuit Breakers—Oil and Air-Blast."[6]

The satisfactory results of these tests were predicted by the laboratory tests. Straight opening tests, *CO*–15 second–*CO* duty-cycle tests and high-speed-reclosing duty-cycle tests were handled without disturbance or signs of distress up to the limits of available short-circuit capacity. The breaker interrupting times are well below three cycles, except in several tests of the second series when one pole of the breaker slightly exceeded this time of interruption. A summary of these times is shown in Figure 10 which includes all phases. The reclosing times were less than 20 cycles, and on the highest duty

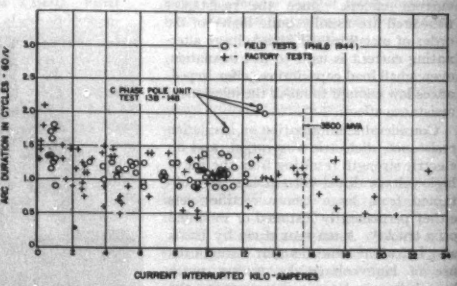

O - FIELD TESTS PHILO 1944
+ - FACTORY TESTS
C PHASE POLE UNIT
TEST 13B - H B
3500 MVA
ARC DURATION IN CYCLES - 60 ~
CURRENT INTERRUPTED KILO-AMPERES

Figure 11. Interrupting performance of 3,500-megavolt-ampere three-cycle interrupters showing arc duration in cycles at various currents

Field tests made on triple-pole breaker at 139 kv. Factory tests made on single interrupter at voltages of 66, 55, 44, 22, and 14.5 kv

there was satisfactory performance with a reclosing time of $15^1/_2$ cycles.

A comparison of the breaker interrupting performance on these full-scale field tests with its performance on laboratory tests is illustrated in Figure 11 which shows the arc durations from the field tests superimposed on arc durations of the laboratory tests. Because of the similarity of results, there is a direct confirmation of the laboratory-test procedure.

The line-de-energizing tests demonstrated the same principle as laboratory tests had shown that only moderate overvoltages, up to 1.4 times normal, were present when interrupting lumped capacitances up to 10,000 kva on a single-pole unit.

Conclusions

1. The performance of the breaker in opening, closing, and reclosing on short circuits approximating 3,500 megavolt-amperes under actual operating conditions justifies the assigned breaker ratings.

2. The field-test results confirmed the testing laboratory procedures imperative to circuit-breaker designers.

3. Actual confirmation of laboratory-test results up to 3,500 megavolt-amperes enables designers to build upon these foundations in the development of 5,000-megavolt-amperes breakers. Although the laboratory-test interruption at 23,000 amperes in Figure 7 corresponds to approximately 5,500 megavolt-amperes at 138 kv, it is fully recognized that the final design of a 5,000-megavolt-ampere breaker would require further development but the present available data give the assurance that such a breaker is practical and can be built when the need exists.

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A Portable Instrument for Measuring Insulation Resistance at High Voltage

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THERE has been an increasing trend toward measuring insulation resistance of high-voltage machines and cables at or above their rated voltage by the use of direct current. The advantage of high voltage lies in its ability to detect leakage paths which do not occur at lower voltages.[1] D-c tests are advantageous because of the elimination of capacitance-current effects. Since the resistances measured are usually quite high—of the order of megohms—if high-voltage alternating current is used to test insulation, even small load capacitances offer impedances low enough to mask the insulation-resistance effect.

Considerable information on insulation resistance, dielectric absorption, and dielectric strength resulting from the use of high-voltage direct current has been obtained from large heavy rectifier sets either permanently installed or mounted on a truck.[2] A ten-year study by Davis and Leftwich[3] indicates that through the use of high-voltage d-c testing much knowledge can be gained concerning the cause of high-voltage generator insulation failures. They report that a majority of generator failures are traceable to mechanical defects, many of which were detected and located before failure in service. Other investigations have explored the field with lower voltages of the order of 500 to 1,000 volts direct current.[4,5]

The study of insulation resistance at high voltages has been restricted by the type of equipment available, which has involved transportation problems and has been very costly. There is considerable evidence that the availability of a portable tester of suitable characteristics would greatly stimulate collection of such data throughout the industry. A suitable portable instrument of rugged construction recently has been made possible by the development of a new cold-cathode rectifier tube. Because a cold-cathode tube requires no cathode heating power, it is well adapted to those applications.

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F. W. ATKINSON is president and ROBERT B. TAYLOR is director of research of the TAKK Corporation, Newark, Ohio.

The authors acknowledge the assistance and criticism of J. S. Askey, J. S. Johnson, and G. L. Moses, engineers of the Westinghouse Electric and Manufacturing Company.

New Cold-Cathode Rectifier Tube

Rectifier tubes employed in this test instrument belong to a new family of high-voltage rectifiers which do not require heated cathodes.[6] They are gas-filled diodes in which the cathodes are composed of an array of fine wire points.

Figure 1 (above). Takktron type 60.8 high-voltage rectifier tube (cold-cathode)

The cathode, when negative, discharges to the anode which consists of a fired-on graphite coating on the interior of the Pyrex-glass envelope.

By controlling the pressure and composition of the gas, the number of points in the cathode, and the anode–cathode spacing, it is possible to provide a wide range of rectifying characteristics. Present standardized tube models will provide d-c outputs up to 25 kv and currents up to ten milliamperes in half-wave circuits.

These tubes are particularly suited for cascade voltage-multiplying circuits since no filament-transformer insulation problems are encountered.[7] Also it is possible to reverse the high-voltage output polarity merely by reversing each tube in its mounting. By use of such voltage-multiplying circuits, practical power units producing up to 200 kv have been built. Even higher voltages are feasible. Such high-voltage power units are characterized by light weight, compactness, and air insulation in the high-voltage portion of the unit. Small high-voltage transformers are used since the maximum alternating voltage required is 30 kv rms.

These tubes are not damaged if their maximum inverse peak voltages are exceeded. Under this condition soft diffuse discharges take place between the cathode and the anode without damaging the tube or its characteristics. Complete short-circuiting of the output of this type of tube, or of a power unit employing the tube, likewise has no harmful effects. The absence of a hot cathode implies no deterioration during idle periods and the ability of the tube to start instantly upon the application of power.

These desirable self-protective properties are gained from the internal resistance of the tube. This resistance has little effect on the output-voltage regulation for load currents within the current rating of the tube. Beyond this value, however, the tube resistance becomes large enough to protect both the tube and the high-voltage transformer. This tube resistance is also advantageous in that it

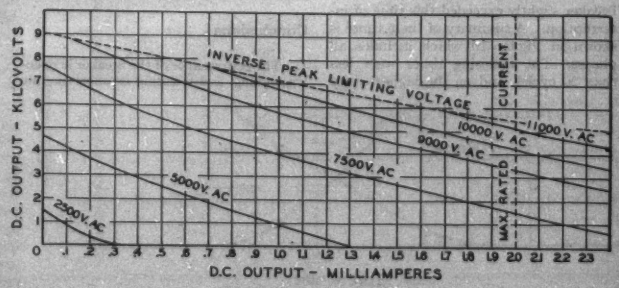


Figure 2. Voltage–current characteristics of Takktron type 60.8 tube

Figure 3 (left). Panel view of aircraft-ignition-cable tester

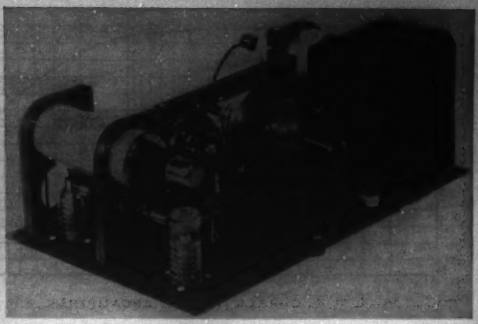


Figure 4. Interior view of tester illustrating ample clearances, rugged construction, and inherent simplicity

aids the filtering of the output voltage, and only small filter capacitances are needed for low-output ripple voltage.

The Takktron type 60.8 rectifier tube shown in Figure 1 has a maximum inverse peak-voltage rating of 21 kv. Its direct output current and voltage characteristics for various alternating input voltages are shown in Figure 2. This tube is designed for a maximum output current of two milliamperes and at this current will provide a direct voltage of five kilovolts. At "no load" the tube will deliver nine kilovolts direct current.

The tube is air-cooled and is mounted in an insulating ring support by means of three rubber *V* blocks equally spaced around the periphery of the enlarged section of the envelope. The tube terminals and the terminal connectors are designed to be free of corona at the tube potentials.

The physical dimensions of the Takktron type 60.8 tube are as follows:

(*a*). Over-all length.....6¼ inches
(*b*). Length of envelope.....4⅛ inches
(*c*). Maximum diameter of envelope.....3¼ inches

Use in Testing Aircraft-Ignition Cable

To assist in evaluating the performance of aircraft-ignition systems, the instrument shown in Figure 3 was developed to measure the insulation resistance of cables and other ignition parts such as magnetos, distributor blocks, heads, fingers, sleeves, and plates at or above their operating voltages. The range of the instrument is 10 to 10,000 megohms measured at any voltage between 2,500 and 15,000 volts. The outside dimensions of the instrument are 10 by 11½ by 18½ inches, and it weighs 31 pounds.

An interior view shown in Figure 4 illustrates the rugged construction of the unit. A schematic diagram is shown in Figure 5. The input to the high-voltage transformer is controlled by a variable autotransformer. The secondary voltage is fed into a voltage-doubling circuit, which is filtered by a 15,000-volt 0.02-microfarad-output capacitor. An adjustable spark gap is provided to prevent overstressing of component parts as well as to limit the output voltage. In series with the gap is a 10,000-ohm resistor to reduce high current surges during flashover. The kilovoltmeter is connected across the high-voltage output of the rectifier.

In series with the grounded terminal is a current instrument with 0–100- and 0–500-microampere scales. A neon glow lamp is shunted across the current-instrument circuit in such a manner that leakage currents in excess of either current range will cause it to flash. This also will occur when current pulses in excess of 100 microamperes or 500 microamperes are of such short duration that the current-instrument pointer is not deflected because of its mechanical inertia. In addition the neon glow lamp serves to protect the sensitive current instrument against short-circuit currents encountered with faulty insulation.

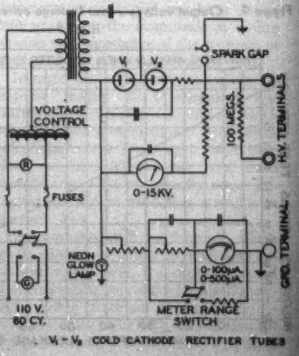
Two high-voltage output terminals are provided, one connected directly to the power supply and the other through a 100-megohm series resistor. The output voltage of the directly connected terminal is indicated by the kilovoltmeter. Figure 6 shows a typical voltage-regulation curve from no load to short-circuit current without adjustment of the voltage control. Because of the tube characteristics the instrument is not damaged when this output terminal is short-circuited at full voltage. The "off–on" switch also may be operated under short-circuit conditions without harm. This terminal is especially useful in both dielectric-absorption and dielectric-breakdown tests. Insulation resistance in megohms may be determined from the expression:

$$\frac{\text{Kilovolt reading} \times 1{,}000}{\text{microamperes}}$$

The value of the neon-lamp resistor may be neglected since it is approximately 0.5 megohm.

The other high-voltage output terminal is used where it is desirable to limit the current in the test specimen. With the internal 100-megohm resistor the voltage across the test specimen is inversely proportional to the leakage current. Figure 7 shows the voltage-regulation curve of this circuit. If the insulation is in perfect condition and therefore has low leakage current, the test voltage is approximately that indicated by the kilovoltmeter. Since aircraft-ignition harness usually is tested at voltages between 10 and 12 kv, the instrument is calibrated in megohms in this voltage

Figure 5. Circuit diagram of aircraft-ignition-cable testers



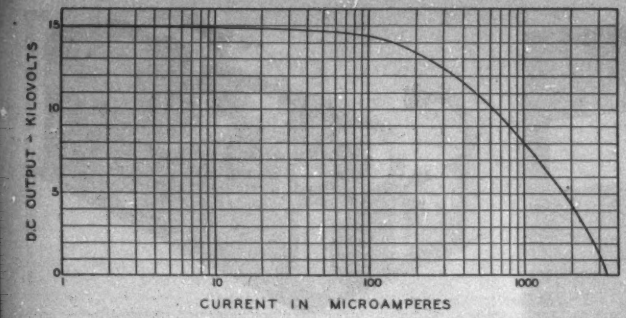


Figure 6. Voltage-regulation curve of aircraft-ignition-cable tester when series resistor is not used

Voltage adjustment unchanged

range. To determine the insulation resistance, the voltage is raised to the test value (indicated by a red dot on the voltmeter scale), the leakage current is noted, and the corresponding resistance is read on the calibration chart on the face of the instrument. Figure 8 shows a typical calibration curve. For other test voltages insulation resistance in megohms may be calculated from the expression:

$$\frac{\text{Kilovolt reading} \times 1{,}000}{\text{microamperes}} - 100$$

Since the rectifier tubes are not in the instrument circuit, it is not necessary to readjust these instruments when replacing tubes.

The series resistance increases the personal safety to the operator, and for this reason instruments with this circuit only are recommended for use by airplane mechanics or others not familiar with high-voltage testing procedures.

Where it is desired to operate the unit from a storage battery, a self-contained vibrator-inverter has been designed to supply 110 volts alternating current from a 12- or 24-volt d-c source. Since no filament power is required, the inverter and the battery drain are small.

Exploratory Work in Industrial Field

Although this instrument now is used primarily for testing aircraft-ignition cable, some exploratory work with it has been done in the industrial field to determine test requirements there. Insulation-resistance and dielectric-absorption measurements have been made on sections of a 25,000-kva 6,900-volt-class vertical water-wheel generator. The winding-to-ground capacitance of this generator is approximately 0.13 microfarad per section or 0.4 microfarad for the entire machine.

Figure 9 shows the dielectric-absorption curves at 10,000 volts for each section and for the entire machine.

Testing Cable

Insulation resistance of a 350,000-circular-mil three-conductor impregnated-paper compound-filled lead-sheath cable, rated at 15 kv, 18,385 feet long ($3^1/_2$ miles), was measured with the instrument shown in Figure 3. Test results were as shown in Table I.

Table I. Insulation Resistance of 350,000-Circular-Mil Three-Conductor Impregnated-Paper Compound-Filled Lead-Sheath Cable Rated at 15 Kv, 18,385 Feet ($3^1/_2$ Miles) Long

AT-13	Voltage, Kv	TAKK Tester (Current, Microamperes)	Resistance, Megohms
Phase *A* to ground	14.8	60	246
Phase *B* to ground	14.0	62	226
Phase *C* to ground	13.8	42	328
A to *B*	14.5	74	196
B to *C*	14.0	57	246
C to *A**	14.5	70	206

* Nothing grounded.

These and other tests indicate that for the industrial field other current-instrument ranges would be desirable. Possible ranges might include a unit for measuring insulation resistance at 2,500, 5,000, 10,000, and 15,000 volts with current ranges of 0–25 microamperes, 0–250 microamperes, and 0–2,500 microamperes. This would result in a unit with an insulation-resistance range from one-half to 30,000 megohms. Other portable testers

Figure 8. Typical instrument-calibration curve of aircraft-ignition-cable tester when protective resistance is used

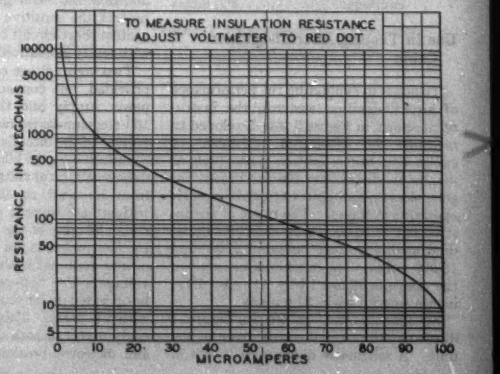
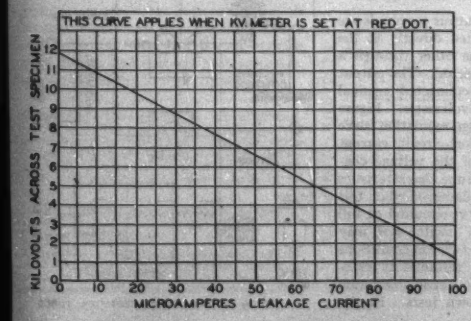


Figure 7. Output voltage versus leakage current when series resistor is used



Standards and Insulation Characteristics of Oil-Insulated Transformers

F. J. VOGEL
MEMBER AIEE

THE STRENGTH of the insulation in transformers to resist various types of voltage stress is very important. The service and life of the transformer is partially dependent on the insulation strength, and in recognition of this fact standards for insulation strength long have been established. In the course of time improvements have taken place in design, new applications have been created, and more has been learned about the nature of stresses which arise in service. Service conditions, too, probably will change in the future, which will require changes in insulation requirements. Therefore it is natural that gradual changes in the standards, and additions to them, have taken place, with the result that sometimes they are not entirely consistent. It is desired in this paper to point out some inconsistencies and propose certain changes in the standards which might be given consideration.

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Partial History of Insulation Requirements

For the purpose of this paper, it is necessary to recall that at one time the standards required a test on the major insulation of two times the rated voltage plus 1,000 volts, and an induced test of two times the winding voltage, with minimum values specified. One of the additions to the standards arose from the electrification of railroads. Railroads use a grounded single-phase system, which led to the use of transformers with relatively little insulation on the grounded end. Without going into detail about the reasoning involved, only an induced test was used replacing both the applied test on the major insulation and the induced test on the winding insulation for this apparatus. The magnitude of the test was specified as 2.73 times the normal operating voltage to ground and was extended to any transformer with one end of the winding grounded, such as transformers for three-phase service with grounded neutral. This procedure was later abandoned and replaced by induced tests at specified levels; more nearly approaching an induced test of 3.46 times the voltage to neutral.

During the period from 1920 to 1930, the effects of lightning on transmission lines, particularly on transformers, became of special interest to utility and manufacturers' engineers. In the early 20's when transformers were damaged, the matter was dismissed on the basis that transformers were struck by lightning, an act of God, and that nothing could be done about it. The transformer designer used extra insulation between turns at the line end as dictated by experience and his own judgment. The major insulation of low-voltage transformers was in excess of that needed for the specified tests, partly because it was not difficult to obtain more insulation and partly because experience showed it necessary. At the end of the 20's, some customers were specifying levels for surge strength, requiring transformers to be stronger than specified lengths of insulator strings, gaps, bushings, and so forth. At that time, transformer designers generally did not have design information on the magnitude of service stresses nor knowledge of the strength of insulating materials to withstand them.

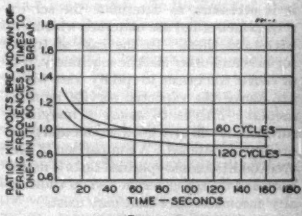

Figure 1

From Figure 23 of reference 1

In order to help clarify this situation impulse testing of transformers was started and levels were established, which were changed several times. It is of interest that these levels were lower than those specified in the late 20's, even though transformers actually were improved greatly in insulation strength in the early 30's.

In a period of such development, where levels often were based on what was expedient at the time, it is to be expected that everything would not be exactly perfect. When machines by one manufacturer are being built with certain claimed design features, it is not always possible to have been developed for operation at 60,000 and 100,000 volts at currents up to five milliamperes.

Conclusion

The TAKK d-c high-voltage insulation tester and insulation-resistance instrument fills a need in the study of numerous types of electrical insulation. Limited experience indicates that it is useful in testing high-voltage cable, aircraft-ignition systems, and high-voltage generating apparatus. It is the belief of the authors that there are many other applications in the electrical industry where a device of this type will be found useful and economical. It is hoped that the availability of this device will encourage the collection of considerable data on insulation testing and insulation resistance which will contribute to a better understanding of the subject and further developments in the art.

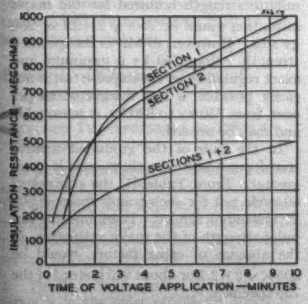

Figure 9. Dielectric-absorption curves for a 25,000-kva 6,900-volt water-wheel generator taken at 10,000 volts

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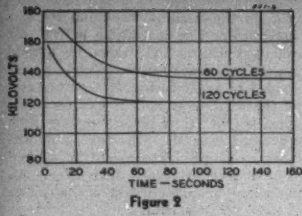

Figure 2

From Figures 13 and 14 of reference 2

to make changes in standards effective at once. This has been recognized more than once by making such changes effective at some later date. Sometimes levels determined are not consistent and unnecessarily effect the design, and it is believed that this situation is partially the case today for transformers. In order to see if this condition exists, I believe the best procedure would be to enumerate all of the service requirements and determine how much insulation would be required to meet them.

Requirements for Transformer Insulation

In the solution of any design problem it is necessary to determine the service requirements and use materials which will withstand them. In the case of transformers and other electric machinery, it is of course the intent to specify tests which are above the expected service requirements. This is to assure a margin of safety that will give good service and good quality of material. A comparison of service conditions and specified tests is useful both as a design criterion and in showing any inconsistencies that may exist.

One of the service requirements for insulation is that it withstand the steady-state voltage to ground from all parts of the winding. In the case of three-phase transformers, this is 57.7 per cent of the line-to-line voltage at the terminals. Since the test required to indicate this strength is the one-minute test, a comparison of the actual strength required, probable one-minute 60-cycle strength, and the tests specified by the standards can be made (Table I).

Table I. Comparison of Normal Service Requirements With Standard Specifications for Insulation

System Voltage	Maximum Normal Service Stress to Ground	One-Minute 60-Cycle Test Equivalent to Service Stress	Specified One-Minute 60-Cycle Test Applied	Specified One-Minute 120-Cycle Test Induced	60-Cycle Test Equivalent to 120-Cycle Induced Test
138 kv.	79.8 kv.	88 kv.	275 kv.	275 kv.	300 kv

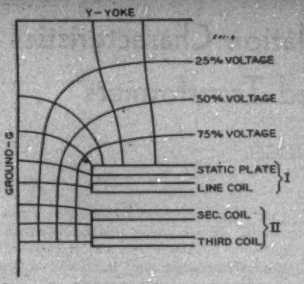

Figure 3. Dielectric field of core-type transformer with all coils at approximately line voltage

I—100 per cent voltage
II—Practically 100 per cent voltage

The equivalent one-minute 60-cycle strength is obtained from reference to Figures 1 and 2 taken from papers by Montsinger[1] and Vogel.[2] The 60-cycle-test voltage equivalent to the high-frequency induced test also is obtained from Figures 1 and 2.

Table I clearly shows that normal service voltages would not require the present test levels. It also shows that the present 60-cycle applied- and 120-cycle induced-test levels are not equivalent.

Another requirement is that transformer insulation withstand line fault conditions. In the case of delta-connected transformers, one line could be grounded, giving full line voltage to ground. In the case of star-connected transformers, depending on line conditions, various voltages could exist. Such data, available in a paper by R. D. Evans and Sherwin H. Wright,[3] are required in the application of lightning arresters and often are calculated for specific applications. In some cases, generator overspeed and other factors enter into the problem. Usually, where further consideration to the question is not merited, it is considered that the maximum voltage from any line to ground may be equal to normal line-to-line voltage or slightly more on ungrounded neutral systems. On grounded systems, 80 per cent of normal line-to-line voltage is assumed as the maximum voltage from any line to ground. On this basis, the comparison in Table II might be made.

The reason for giving these tabulations is to show the big margins now available. It would seem that the major insulation is not stressed greatly under normal or fault conditions. Indeed these are not limiting features. This has been recognized by some operators, where willingness to use lower-than-standard voltage tests and insulation levels has been expressed, provided impulse protection was afforded.

Another consideration is that of switching surges and arcing grounds,[4,5,6] giving overvoltage values anywhere from $2^1/_2$ to 5 or 6 times the normal voltage to neutral. The higher voltage values in the range are apparently rare occurrences. In the case of a 138-kv system, switching surges would be anything from 280-kv up to 680-kv crest. These surges, generated in the transformer and line reactance and the capacitance of the system, have frequencies of oscillation low enough so that reasonably uniform voltage distributions will be obtained in the transformer windings.

No standard test to simulate switching surges or even to verify the strength of transformers against these surges has been made commercially, although experiments have been conducted which determine the probable strength of transformers for switching surges.[6] Very few, if any, transformer failures attributed to switching surges ever have occurred. Even those transformers built before 1930 with low levels of impulse-voltage strength have had few, if any, switching-surge failures. Many of the transformers of the 138-kv class had levels of 500-kv and less, instead of the 750-kv now standard. This fact confirms that the voltage distribution of switching surges in windings is fairly uniform as inferred previously.

The conclusions from the above are that transformers will withstand switching surges as limited by the lightning protection used, since the voltage distribution in the windings approaches uniformity, and the impulse and switching surge strength of the transformer insulation to ground are approximately equal.

The last factor to be considered is that of impulse or lightning surges. The impulse test levels now specified for transformers are intended to be values not exceeded in service.

The test levels for impulse strength are standardized and for the 138-kv class are 750 kv for a chopped wave of three-microseconds duration and 650 kv for a full wave. Several observers[3,7,8] have determined the impulse ratio of oil-impregnated insulation as 2.1 or better. If a fair average be 2.1, the 60-cycle one-minute strength required for the major insulation would be $750/\sqrt{2}\times 2.1$ or 250 kv rms. However, 275 kv is the specified strength. Since 750 kv is minimum and exact regulation on the impulse test is not easily possible, a test margin of 10 per cent, from 750 kv to 820 kv, is reasonable and may be needed.

In the case of the grounded neutral transformer, however, the margin is much greater. From Table II, the equivalent 60-cycle test for such transformers is 305 kv instead of 275 kv. Therefore, the impulse strength of the major insulation, in the absence of other factors, would be $305\times\sqrt{2}\times 2.1$ or about 915 instead of the 750 specified.

However, such specified levels do not necessarily insure the ability of a transformer to withstand all service conditions.

Even if lightning arresters are mounted on the units and as close to the terminals as possible, some very high overvoltages can occur but for very short times. If the arrester be 25 or 30 feet from the terminals and the wave front is steep, an appreciable voltage reflection may take place at the bushing terminals. A transformer will withstand such higher voltages if of short enough duration. For example, typical oil-impregnated transformer insulation can withstand 125 per cent of the three microsecond strength for one microsecond. No test is made to prove this fact for the transformer as a unit at the present time, although it is stated in the literature.[5]

If we summarize the above requirements and tests, we see from Tables I and II that the applied 60-cycle dielectric tests and 120-cycle induced tests are far more severe than any steady 60-cycle fault or switching-surge voltage to be expected in service for ordinary transformers and might safely be reduced. We also see that the 120-cycle induced test of approximately 3.46 times the voltage to neutral for grounded-neutral transformers is more severe than the two times normal line voltage for transformers for ungrounded service, although probably the service is more severe, both for the major insulation and the winding insulation, for transformers for ungrounded service. Apparently also we can dismiss the effect of switching surges, since, even if they were of the same magnitude as impulse test waves, they would be more uniformly distributed through the winding. The major insulation for grounded-neutral transformers is higher than required to meet impulse tests. This is another inconsistency in the present rules. Also, no test is specified to insure high impulse strengths for short times or for steep waves, even though such strength may be desirable and may be available.

Since impulse levels determine the insulation provided for both grounded-neutral and ungrounded-neutral service, it would be interesting to see what comparison there would be between two extreme types of transformers built to the same impulse strength.

Strength of Different Types of Transformer

Shielded Transformer for 138-Kv Service

If we define a shielded transformer to be one in which the distribution of voltage in the dielectric field adjacent to the high-voltage-line coils is the same both for impulse voltages and 60-cycle voltages, then we can draw the following conclusions:

1. The 60-cycle strength of the major insulation is in the order of 275 kv, which is greater than required for service.

2. The strength against switching surges is ample.

Table II. Comparison of Fault Requirements With Standard Specifications for Insulation

System Voltage	Maximum 60-Cycle Fault Stress to Ground	One-Minute 60-Cycle Strength—Equivalent to Fault Stress to Ground	Specified One-Minute 60-Cycle Test, Applied	Specified One-Minute 120-Cycle Test, Induced	60-Cycle Test—Equivalent to 120-Cycle Induced Test
138-kv ungrounded neutral	138 kv	154 kv	275 kv		
138-kv grounded neutral	110 kv	122 kv	275 kv	305 kv	

3. The impulse strength for waves chopped after three microseconds is higher than test levels.

4. The steep-front-wave voltage strength should be higher than the three-microsecond strength and at least 1.25 times that value.

Unshielded Transformer for 138-Kv Service

Figures 3 and 4 show the coil arrangement for typical circular-coil-type transformers. The figures show only the outer part of the coils, and G represents the outer leg of the iron circuit and Y the top yoke. G could be either the outer leg of the core or an approximation to the adjacent winding stack. The figures are sections of the windings and show only the outside of the coils. There is a connection on the outer turn of the line coil to static plate and between the outer turns of coils 3 and 4, 4 and 5, and so on. The inner turns of coils 1 and 2, 3 and 4, and so on are not shown.

In Figure 4, a design has been chosen with less than three per cent of the winding between the finishes of the line and second coil. Hence there would be about three per cent of the induced voltage between coils on the induced test. Likewise on steep-wave-front tests we could have as much as 50 per cent of the surge voltage between these coils. In order for the stress between coils to be 50 per cent of the total surge voltage, a poor distribution factor would be required. This factor is a function of the capacitance of the entire column of coils to ground and the coil-to-coil capacitance along the stack. This poor factor was chosen to give an extreme condition.

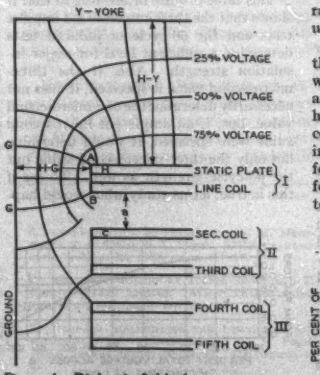

Figure 4. Dielectric field of core-type transformer with extreme voltage concentration at line end

I—100 per cent voltage
II—50 per cent voltage
III—25 per cent voltage

In Figure 4, A and B are corners of the static plate and line coil respectively and are connected together to form the line terminal. In order to determine the strength of such an assembly, and to determine the clearance necessary, a study of the voltage gradients at A and B was made. The conditions were that HY was 4, H-H was 2, and A-B was $^3/_4$ inches, which are common proportions. The distance from B to C, and the voltage from B to C are variable. In the first test, the gradients along AG and BG were kept alike and the distance and voltage from B to C varied. The results of this test are as shown on Figure 5; also, one test was made where the distance a was kept at unity, the voltage varied, and the gradients measured at both A and B. The results are shown on Figure 6. The tests were made by placing electrodes in a water tray and measuring the voltage drop from the corners of the electrodes to a fixed radius. Vacuum-tube voltmeters were used.

Figure 5 shows that, if a is four inches the same as HY, the stress at A and B would be alike with the same voltage across both HY and a. On the other hand, if the voltage at a is about 50 per cent of that across HY, a distance of $1^1/_2$ inches would be required. Further, it was found that the actual strength to ground for all conditions of Figure 4 was some 93 to 94 per cent of what it would be with a

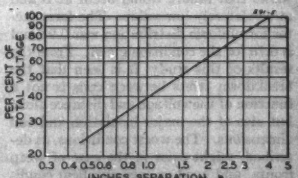

Figure 5. Voltage between line coils for different coil-to-coil clearances and for equal gradients at static plate and line coil

Table III. Relative Strengths of Typical Transformers

Type of Stress	Insulation Strength of Transformers—138-Kv Class: Fully Shielded Transformers — Transformer for 120-Cycle Induced Test, Kilovolts	Fully Shielded Transformers — Transformer for 60-Cycle Applied Test, Kilovolts	Unshielded Transformers I* — Transformer for 120-Cycle Induced Test, Kilovolts	Unshielded Transformers I* — Transformer for 60-Cycle Applied Test, Kilovolts	Unshielded Transformers II** — Transformer for 120-Cycle Induced Test, Kilovolts	Unshielded Transformers II** — Transformer for 60-Cycle Applied Test, Kilovolts
60 cycles	302 rms	275 rms	302 rms	275 rms	302 rms	275 rms
Full-wave impulse	650–900 crest	650–820 crest	650–900 crest	820 crest	<840 crest	<760 crest
Three-microsecond impulse	900 crest	820 crest	900 crest	820 crest	<840 crest	<760 crest
One-microsecond impulse	1,120 crest	1,020 crest	<1,050 crest	<950 crest	<1,050 crest	<950 crest

* Unshielded I has line coils with few turns so that the impulse penetrates into the winding when the front is 1½ to 2½ microseconds.

** Unshielded II has line coils with turns so that the distribution for even 1½-microsecond fronts is wholly due to the capacitance between coils and turns.

uniform distribution as in Figure 3. In other words, if we had a uniform distribution, we would have an impulse strength of about 820 kv with a 275-kv 60-cycle one-minute test and an impulse strength of about 760 kv for conditions similar to Figure 4.

In a previous paper,[8] the use of "form factors" to estimate the strength of insulation arrangements in terms of a standard arrangement was used. Therefore, the form factor is a measure of the relative strength of the parts and without further consideration of exact values can be used to determine the relative strength of different parts of the winding. This form factor may vary when showing the relations of the stresses under 60-cycle and surge conditions in the same transformer. As an example of this, the form factors for the perfectly shielded transformer are the same for both 60-cycle and impulse stresses, and the stresses are relatively the same for both conditions. For the transformer of Figure 4 and under conditions of 60-cycle stress, the form factor would be 0.93 and the highest stress at A. Under surge conditions, if similar to those shown in Figure 5, the form factor would be 0.87 for steep wave fronts.

From Figure 6, conditions could be even worse, since, if the stress from A to B is large, the stress at B increases rapidly. For example, if the distance a is one inch and the stress across a is 70 per cent of the voltage from H to Y or A to G, the form factor at B is 0.70 which shows that failure would occur at B and at a relatively low value. The form factor for uniform distribution was 0.93 and is 0.70 for the condition given. From the results of this study, it is seen that the breakdown stress between coils is not a function of the voltage and distance alone but also of the major insulation and coil dimensions. The worst conditions, as described, might exist in the case of steep fronts, and good or even excellent conditions might exist for slow fronts.

There is still one other point which must not be overlooked. Even were the form factors the same at points A and B, if the strength of the insulating materials used is lower at B than A, the actual strength of the assembly under impulse conditions will be lowered. If we grant, however, that the insulation materials used at A and B are the same, we can determine the relative strengths of some typical transformers as shown in Table III.

In order to make the information in the Table III clear, let us consider the transformers designated as unshielded II.

The grounded-neutral transformer might be tested at 120 cycles for one minute at 275 kv or the equivalent of 302 kv, if tested at 60 cycles. Its impulse strength if the stress at both A and B were alike, would be $302 \times \sqrt{2} \times 2.1 \times 0.87/0.93$ or 840 kv. Likewise, at one microsecond, the strength would be 1.25 times 840 kv or 1,050. Actually values less than these are to be expected.

This table is quite interesting in that it shows that the three-microsecond impulse tests and the 60-cycle or induced tests determine a sufficient level for major insulation strength. Also, if the three-microsecond value is specified, it does not necessarily determine the one-microsecond value, but, if an ample one-microsecond value were specified, it would determine not only the three-microsecond value but the 60-cycle strength as well. To see if this is true, let us study what would happen if a 1,050-kv test were specified at one-microsecond. If this were specified for both grounded-neutral and fully insulated transformers, a 60-cycle level of at least 275 kv would be required for all types, and the 750- to 820-kv three-microsecond level would be automatically obtained. The inconsistency between the 120-cycle and 60-cycle tests would be removed. The latter would be true also, if the three-microsecond values were specified.

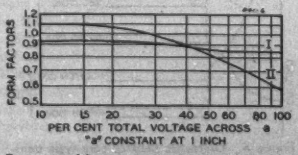

Figure 6. Variation in gradient at static plate and line coil for constant clearance between line coils and varying voltage between coils

I—Form factor at A
II—Form factor at B

At the present time, 650 kv is specified for the full-wave value. This is an independent and arbitrary value and determines the winding strength in the middle and grounded end.

Experience has shown that ability to withstand the applied 60-cycle test or 120-cycle induced test is no proof of a transformer's ability to withstand impulse tests. Therefore, it would be desirable to apply impulse tests to all transformers as a specified commercial test. It would be desirable to change the present tests, if any economies would result and if the testing procedure would be simplified. It is suggested that a three-microsecond, a one-microsecond, or a steep-front impulse test might be substituted for the present applied or induced tests. Since the full-wave test is necessary, it should be retained. Probably it would be desirable also to retain a two times induced test as a last test for all transformer windings. If the one-microsecond test at the correct level were used, it would ensure the three-microsecond value without making another test.

Incidentally, it is believed that very few failures are caused by 60-cycle or induced test at the factory, and practically all insulation troubles are found on either the steep-front or full-wave tests. Practically no failures are found on the three-microsecond chopped test.

Conclusions

It has been shown that an adequate one-microsecond or steep-wave-front strength of transformers also ensures both an adequate value of three-microsecond strength and 60-cycle strength, and avoids inconsistencies existing at the present time. It should, therefore, be possible to substitute impulse tests on transformers giving either a one-microsecond or three-microsecond value for the present 60-cycle applied or the high-frequency induced tests.

The present full-wave values still should be specified to ensure adequate strength against this type of surge. As further insurance, it is suggested that all over-potential tests at low frequencies should not be abandoned, and that a test of two times normal voltage be induced in all transformers. It is suggested that the tests recommended here be studied by the AIEE transformer subcommittee with a view to changing the present standards.

The Dielectric Strength and Life of Impregnated-Paper Insulation—IV

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STUDIES of the causes and mechanism of the failure of impregnated-paper insulation are commonly obscured by the burning due to the final complete breakdown. In a number of years of study of the more accessible properties of impregnated paper and their relation to stability and breakdown, constant attention has been given to the restriction of this burning and a nearer view of the beginnings of failure. Simple fuses and even rapid circuit breakers in the primary circuit of the testing transformer are of no avail. Some improvement is obtained by the use of a thyratron in the grounded lead of the sample with suitable connection to a rapid circuit breaker in the primary. But by far the best results, and indeed very complete success, have been reached by a method for detecting the first occurrence of gaseous ionization within the test specimen. This method is a development of the pioneer work of Paine[1] and the subsequent applications of Arman and Starr and of Whitehead and Shaw,[2] using resonance methods for following the oscillations which arise in the ionization of gas spaces in the insulation wall. New features which have been added are increased sensitivity, improved balancing of the Schering bridge for the frequency of maximum oscillations, the use of greater amplification, and a sensitive recording instrument for registering the first occurrence of internal ionization. The complete setup, as described in this paper, is called the "ionization recorder." With this instrument it is possible to detect the beginnings of failure in a completely impregnated specimen initially free of gas spaces or voids, often to within one layer of the impregnated structure, and also to follow its growth, with interruption at any desired stage on the way to complete breakdown. So far, the instrument has been applied only to the study of the influence of paper density on dielectric strength and stability, and the comparative behavior of two types of paper and two types of oil. From the results it will be seen that a very intimate picture of breakdown and its causes is presented.

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Purpose

Earlier studies[3,4] on paper density showed clearly that for four papers ranging in specific gravity from 0.74 to 1.18, and for two oils, one light and one heavy, there is for each oil a pronounced decrease in dielectric strength with increasing paper density. A sound rational explanation of this result is found in much evidence that failures begin in the oil channels, and in the fact that the stress in these channels increases with increasing paper density due to the differences in the values of dielectric constant in paper and in oil.

Notwithstanding these clear-cut experimental results, many cable engineers state that experience has shown that the use of high-density paper in certain high-voltage cables increases dielectric strength. However, there is little or no published evidence in support of this view, except perhaps as regards breakdown tests of impulse type, and even in that case the picture is not clear.[5]

In possible explanation of this conflict of evidence it should be noted that in our specimens no gas pockets or bubbles are present, and in other respects they resemble the insulation of oil-filled cables far more closely than that of the solid cable. As a consequence no gaseous ionization is present in our tests, and breakdown stresses are well above those encountered in cable practice.

In the earlier studies referred to[3,4] an accelerated step-voltage test was used, the specimens being immersed in the oil under study at a constant temperature of 40 degrees centigrade. Breakdown occurred after two to four days at stresses up to 900 volts per mil. The chief purpose of the tests now reported has been to check the results of the earlier relatively long-time step-voltage tests, with others in which high stress is applied rapidly (two minutes) with resulting breakdown in a few minutes, thereby greatly reducing the influence of time as a possible factor in the earlier studies. For this purpose it was deemed sufficient to use only two grades of paper, namely, grades *B* and *D* of the earlier work.

Other results of interest are the stress-time curves of each paper impregnated with each oil, for short ranges in the neighborhood of breakdown; noticeable differences in two lots of supposedly identical paper from the same manufacturer; and further observations on the causes and mechanism of failure, based on careful dissection and oil extraction of numerous specimens suffering partial failure at various stages up to complete breakdown.

Test Specimens and Materials

The test specimens consisted of 16 layers of five-mil cable paper one inch wide, spiralled cable fashion on a smooth

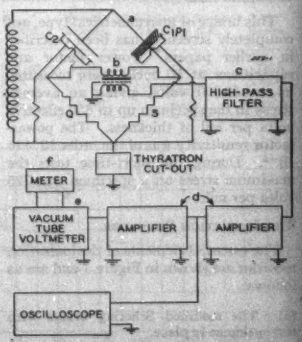

Figure 1. The ionization recorder

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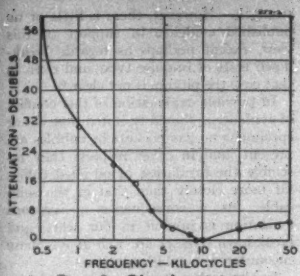

Figure 2. Filter characteristic

brass tube, one inch diameter, 48 inches long, with 33⅓ per cent overlap and nominal ³/₁₆-inch channel width. The lead-foil central electrode (16.5 inches long) was flanked by overlapping guard electrodes extending halfway up the narrow-angle reinforcing end cones.[6]

The paper was furnished by a well-known manufacturer in two values of density; nominal values of specific gravity were: type *B* paper, 0.86; type *D* paper, 1.10.

Two oils were studied; one (5314) was a thin oil as used in oil-filled cables, having values of viscosity at 40, 60, and 100 degrees centigrade of 17, 8.2, and 3 centipoises, respectively, while the other (5317) was a heavier oil as used in solid cables, having values of viscosity at 40, 60, and 100 degrees centigrade of 480, 120, and 18.3 centipoises, respectively.

In general from three to nine identical specimens were tested for each combination of paper and oil, or for other variables studied.

For other details of the experimental equipment, methods of drying, impregnation, temperature control, and electrical measurements, the earlier papers[3] may be consulted.

The Measuring Equipment

Schering Bridge

This bridge of unsymmetrical type, and completely screened, has been described in earlier papers.[7] Power factor and capacitance at 60 cycles were measured up to 52,000 volts, giving an average stress in the specimen up to 650 effective volts per mil of thickness. The power-factor sensitivity was of the order 10^{-4} to 10^{-5}. During the short-time tests the maximum stress on a specimen was 725 volts per mil.

The Ionization Recorder

The essential elements of the ionization recorder are shown in Figure 1 and are as follows:

(*a*). The modified Schering bridge with test specimen in place.

(*b*). A bridge output transformer with electrostatic shield between primary and secondary, and with both windings balanced as to capacitance to ground, permitting the grounding of one terminal of the secondary coil without upset of the symmetry of the bridge circuit.

(*c*). An attenuator and a high-pass filter, whose characteristics are shown in Figure 2, matches as to impedance with the bridge transformer.

(*d*). A three-stage vacuum-tube amplifier.

(*e*). A bridge-type vacuum-tube voltmeter.

(*f*). A d-c recording milliammeter giving full-scale deflection for one milliampere, connected across the output terminals of the vacuum-tube voltmeter.

With the recorder connected, a specimen in place in the bridge, and a stress of 400 volts per mil applied, a small reading was found on the recorder. Its magnitude, from one to three per cent of the maximum reading encountered in the tests, showed no appreciable variation within the range of stresses used. With the specimen replaced by an air capacitor the small reading was still present and was found due to minute discharge points on the disconnecting switches and other parts of the high-voltage circuit. Since these discharges could not be eradicated completely, all recorder readings are based on this zero disturbance as datum line. Further, they were found useful for balancing the bridge, obviating the necessity of an auxiliary discharge gap for this purpose.

As shown in Figure 2 the filter effectively cuts out all frequencies below 3,000 cycles. The complete recorder circuit was found to be most sensitive in the region of 9,000 cycles. This is within the range of dominant frequencies of the gaseous discharge in cable insulation as found by Bennett, Paine,[1] and others. Thus the recorder receives the amplified, rectified, and integrated d-c record of frequencies above 3,000 and up to 16,000 cycles per second arising in a gaseous discharge in the specimen under test, and appearing at the output terminals of the bridge, the latter being balanced for minimum zero reading. The initial sensitivity of the bridge and recorder at 9,000 cycles was one division of the recorder scale per 18 microvolts at the transformer input terminals.

The initial sensitivity of the recorder was also measured in terms of the first discharge over a small air gap between plane surfaces. The gaps consisted of thin sheets of mica or lead foil with circular holes cut in them, mounted between thin sheets of glass. The gap was placed in parallel with an air capacitor, in place of the test specimen in the bridge circuit. On raising the voltage, visual discharge of the gap takes place at a sharply marked voltage, and with an immediate reading on the recorder. Table I gives the recorder readings for these initial discharges for three sizes of gap. From these simple data it appears that the recorder gives a response of about 0.8 to 0.9 division per square centimeter area of a 0.2-millimeter gap, and that the response is roughly proportional to the area of the gap.

Table I

Cell Number	Thickness of Film, Cm	Area of Film, Sq Cm	Deflection Scale Divisions	Deflection Per Sq Cm
1	0.021	10.96	8.50	0.78
2	0.022	2.85	2.25	0.79
4	0.014	1.27	1.25	0.98

Experimental Results

Initial Gaseous Ionization

In using the ionization recorder for the study of breakdown in impregnated paper the approach to failure is usually seen to be divided into three well-defined stages. The first is a slow (one minute) rise of the trace of the needle above the zero line. This indicates the beginning and slow growth of a spot of internal ionization. It is best observed at from 50 to 100 volts per mil below the maximum rapid breakdown value. With no further increase of stress the record flattens out into a second stage of constant value of internal ionization which may continue for hours, indicating a temporarily stable condition. However, something progressive is obviously taking place, for there comes a time when with no further increase in stress the

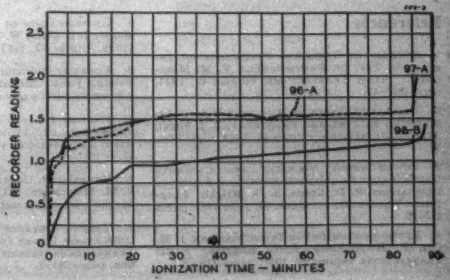

Figure 3. Ionization curves showing three stages in the variation of ionization with time

Paper *D* and oil 5317 at 600 volts per mil

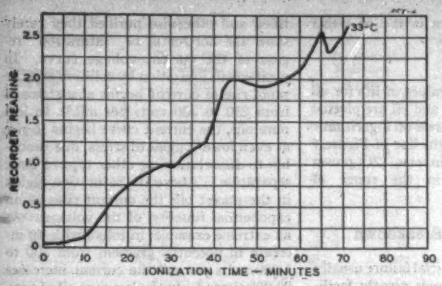

Figure 4. Ionization curve showing the nearly uniform rate of increase of ionization with time at very high stress

Paper *E* and oil 5314 at 800 volts per mil

record begins another rise which ultimately leads to breakdown, sometimes within a few minutes or even seconds. The boring action of the ionization has advanced so far that equilibrium is upset, and cumulative increase of stress on the still-undamaged portion of the insulating wall sets in. Figure 3 shows three good examples of the three stages, taken at 600 volts per mil on three identical specimens of *D* paper and oil 5317. Although there is some spread in shape and values the three stages are clearly seen in each case.

The duration of each stage is shortened rapidly with increase of applied stress. As the rapidly applied (two minutes from 100 volts per mil to full value) stress is increased, stages 1 and 2 disappear, ionization begins at once, and failure follows soon in stage 3. Figure 4 shows such a case, *E* paper,[3] 5314 oil, 800 volts per mil. This type of record is chiefly of interest as showing that even short-time failures are progressive with rapidly increasing volume of internal ionization. Thus for shorter and shorter duration of stress application, and ultimately impulse test, higher and higher values of stress are indicated for complete penetration over the ionization path.

If complete breakdown is allowed to occur the recorder needle goes off scale and the transformer primary circuit is interrupted by the thyratron circuit. In this case there is considerable burning in the path of the failure, although the thyratron usually interrupts before complete puncture has taken place. The ionization recorder, however, provides at once an indication of approach to breakdown and the circuit may be opened at any stage. In this way partial failures only are allowed to occur, and the growth of the internal gaseous ionization and its attack on the oil-paper structure may be closely followed by subsequent examination of the specimens. In most cases the failures extend through from four to six layers, but many instances in which only one or two layers are involved have been encountered.

New *B* and *D* Papers

It was necessary to obtain new lots of both *B* and *D* papers; they were furnished by the same manufacturer as the earlier lots, and on the same specifications. They agreed closely, in both density and thickness with the earlier papers, but certain differences were noticed in handling and assembling, principally in the matters of springiness or stiffness. Both the new papers were tested therefore with the same program of accelerated step tests as the old, using 5314 oil. The results of these check tests on six specimens of the new *B* paper and three of the new *D* paper are given in Table II. Comparison with the earlier tests shows that the earlier *B* paper had an average maximum-life stress of 713 volts per mil, and the later *B* paper 652 volts per mil, that is, the former 61 volts per mil or 9.3 per cent the better. There was no appreciable difference in the results on the two lots of *D* paper.

Influence of Paper Density

The approximate breakdown value of each type of present specimen was known from the earlier step tests, and from preliminary ionization-record tests. However, in order to lessen the uncertainty caused by the inherent spread of observed short-time intervals, it was decided to extend the range of observations over several values of stress in the neighborhood of the nominal maximum breakdown value. In this way breakdown stress–time curves are obtained with clearer pictures of the differences, if any, in the behavior of the two papers as the time of application of breakdown stress becomes shorter and shorter. Consequently, breakdown tests were made on each paper impregnated with each oil, at three values of stress, with results as indicated in Figures 5 and 6, and with accompanying ionization-time records. Table III gives the results of nine tests on *D* paper impregnated with the heavier oil. Table IV gives the average values for all tests on both papers and both oils. The curves of Figures 5 and 6 are plotted from the values in Table IV.

The sequence of observations was as follows: On switch closure a stress of 100 volts per mil was applied immediately, and then increased uniformly so as to reach the test value within two minutes. The ionization recorder was then cut in and its record followed, noting the condition of the specimen as regards the volume of internal ionization, and the successive stages marking the approach to failure. Immediate approach to failure is indicated by a rapid rise of the ionization record in the third stage of the curve of Figure 3. Most of the tests were interrupted a few seconds before complete puncture to avoid burning and to obtain a "partial" failure, yielding a much clearer picture on subsequent dissection of the specimen.

The curves of Figures 5 and 6 show that the influence of paper density reported in the earlier paper,[4] using a voltage step test, is confirmed by the present short-time tests, namely, breakdown stress and life are lower for the denser paper. If the two curves for the *B* paper are raised by 60 volts per mil to correct for its difference with the old *B* paper, the amount of the lowering is seen to be closely the same as in the earlier work. In the case of the 5314 oil the amount of lowering is practically the same for the lower stresses and longer times, becoming somewhat less as the test stress is raised. Using 5317 oil the amount of lowering is more or less uniform at the value found in the earlier work, except perhaps for the highest stresses where there is some indication that the curves may approach each other at still higher stresses.

Table II. Comparison of Old and New *B* and *D* Papers

Paper	Specific Gravity	Breakdown Stress, Volts Per Mil	Life, Hours
Old *B*	0.83	713	75.5
New *B*	0.80	652	63.6
Old *D*	1.14	573	48.9
New *D*	1.10	564	47.0

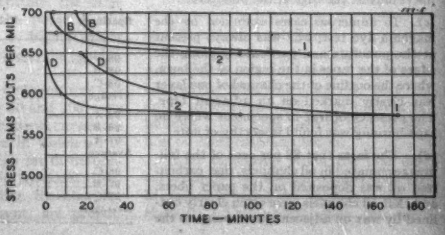

Figure 5. Variation of life and time to start ionization

Papers *B* and *D* impregnated with oil 5314

1—Life

2—Time to start ionization

Power Factor

The increase of power factor with increasing paper density noted in the earlier work is also found in the present tests. Of particular interest are the observations of power factor (measured at 300 volts per mil) before and during the course of the tests which show that the effects of foregoing ionization have little effect in increasing power factor until well into the neighborhood of failure. In one case in which the ionization stress was 600 volts per mil, the power factor over the range 200 to 500 volts per mil was substantially constant at 0.0032; after 75 minutes at 600 volts per mil and very copious ionization for 7.5 minutes and breakdown imminent, the power factor was found to be 0.0041. In another step-voltage test the power factor at 400 volts per mil was 0.00449; after 28 hours at 482 volts per mil the value was 0.00430; after 39 hours at 529 volts per mil the value was 0.00510. The specimen failed at 529 volts per mil and 39.43 hours; a power factor reading was taken two minutes before failure, with value 0.00685. Thus even in the neighborhood of failure the value of power factor remains very low. The deterioration due to ionization in the approaching failure must be confined to very small volumes of insulation and ionized gas.

Post-Mortem Examinations

In a foregoing paper[4] the results of the examinations of 117 cases of failure were reported, with very clear evidence that initial failure usually occurs in oil channels or films. Similar evidence has been found in the post-mortem examinations of 65 failures in the present work. Of special interest are 6 incipient failures, involving only one or two layers, and reaching neither electrode, or only showing wax on paper edges of oil channels. In all these cases ionization as indicated on the recorder was well advanced before interruption of the test.

The important facts about the failures are:

(a). Of the 54 punctures reaching an electrode, 88 per cent terminated in an oil channel, 79 per cent of these at the central brass conductor.

(b). Microscopic examination of many burned areas disclosed the presence of removable carbonized oil particles on and among the paper fibers, with scorching of the fibers only at the edge of the puncture.

(c). In numerous cases examined by the magenta-dye test, wax was always present at the puncture and particularly along the edges of the tapes in the region of the burn, where the outline of the channel of one layer was clearly marked on an adjacent tape. The presence of wax in specimens where no tape burning was found is worthy of note.

(d). The facts that 88 per cent of the failures terminated in oil channels, that carbonized oil was deposited on the paper fibers, and that oil channels were often clearly outlined by wax on adjacent tapes point to the beginning of breakdown in the oil rather than in the paper fibers.

Stress–Life Curves

When the average values of life for all combinations of paper and oil are plotted against the values of stress on logarithmic co-ordinates, the straight line of Figure 7 results, indicating an inverse 12th-power stress–life variation in the range of stresses studied.

The Mechanism of Breakdown

The certainty that initial failure usually occurs in the oil channels greatly facilitates the drawing of the picture of the mechanism of complete failure. The properties of insulating liquids, and especially of petroleum oils, have been widely studied and their behavior under various conditions of electric stress, pressure, and temperature, are well known. For our present purpose we need only invoke three conspicuous properties of insulating oils, namely:

1. Electrical conductivity and the d-c volt-ampere curve.

2. Space charge accumulation and its influence on potential gradient.

3. The influence of pressure and of temperature.

The Volt–Ampere Curves of Oils

There are illustrated in Figure 8 volt–ampere curves (a) for a high-grade insulating oil, (b) for the same oil carefully purified, and (c) the effect of successive redistillations in a closed system. Obviously the regions of rapid current increase are due to secondary ionization in the oil, that is, a progressive liberation of more free liquid ions. In the purest states the curves are identical in shape with the corresponding curves for a gas (although the ranges of values are different), and as in gases so in liquids the upturn of the curve is due to ionization by collision of electrons with neutral atoms and molecules of the oil. Cable oils, especially after contact with the paper and copper, have rather the characteristics of type (a) than of types (b) and (c); unless redistilled and otherwise purified they rarely show the horizontal or "saturation" region of the current–voltage curve. In purified oils ionization by collision and the rapid rise of current begins at a stress of from 250 to 300 volts per mil.[5] In less pure oils, the current curve begins to rise at even lower values of stress, due probably to dissociation, or other type of ionic separation. Above the saturation region in the purest oils the current rises as an exponential function of the voltage. As an extreme example, in toluol with an increase in potential gradient from 300 to 1,000 volts per mil the current increases 20,000 times.[6] In the less pure oil of type (a), ionization is well under way at 250 volts per mil and the current has already a relatively high value and increases four times as the stress rises from 250 to 300 volts per mil.

The ions of the saturation region are most commonly due to residual dissociated impurities. These are increased by contact with other materials, for example, paper and copper in the impregnation process, thus accounting for a change of the oil to type (a). The upturn of the current curve is due to collision of electrons liberated in the oil and at the electrodes, and moving with high velocities, with the neutral atoms and molecules of the oil, thereby causing a cumulative increase in the number of ions of both signs.

Space Charges

The accumulation of space charges near the electrodes in a gas at low pressure in which electrons are being liberated is well understood. A similar phenomenon takes place in a liquid under high electric stress. However, the mass of the liquid ion is so great and its specific velocity so small, that it appears more likely that the well-known accumulation of ions, and consequent high potential gradients at the electrodes of an insulating oil are due to clouds of ions surrounded by neutral molecules, and unable to escape to the electrodes.[9] As the stress or temperature rises, more and more of these ions are liberated from the enveloping neutral molecules, with corresponding contributions to the increase in current.

Table III. *D* Paper, 5317 Oil

Specimen	Breakdown Stress, Volts Per Mil	Time to Start Ionization, Minutes	Duration of Ionization, Minutes	Life, Minutes
98-*A*	650	0	33.0	33.0
98-*B*	650	0	19.0	19.0
98-*C*	650	0	18.5	18.5
Average	650	0	23.5	23.5
96-*A*	600	0	59	59
96-*B*	600	2	86	88
97-*A*	600	0	86	86
Average	600	0.7	77	77.7
96-*C*	500	55	378	433
97-*B*	500	614	32	646
97-*C*	500	648	790	1,438
Average	500	439	400	839

Table IV. Average Values, All Tests

Breakdown Stress Volts Per Mil	Time to Start Ionization, Minutes B	Time to Start Ionization, Minutes D	Duration of Ionization, Minutes B	Duration of Ionization, Minutes D	Life, Minutes B	Life, Minutes D
Oil 5314						
700	4.5		10.3		14.8	
675	5.5		17.2		22.7	
650	95	0	34	17.1	129	17.1
600		7.9		54.9		62.8
575		95.1		77.4		172.5
Oil 5317						
650	0	0	29.6	23.5	29.6	23.5
600	11.3	0.7	125.7	77	137	77.7
500	617	439	293	400	910	839

Under alternating stresses below say 200 volts per mil, in the oil channels of impregnated paper, these space-charge layers oscillate back and forth with the frequency of the applied stress. At very low stress the amplitudes of oscillation are small. With increasing stress the amplitudes increase, until ultimately some of the ions reach the boundary of the channel. Motion is arrested, and space charges accumulate, with increase of potential gradient over the oil–paper interface. The velocities of ions in cable oils at 20 to 30 degrees centigrade are of the order 10^{-4} centimeter per second per volt per centimeter; at the stresses here in question the velocities are quite high enough to permit practically complete passage of the ions back and forth over the whole thickness of the channel, in one 60-cycle period. In the lower range of stress this oscillating motion of space charges causes the component of loss due to the oil and contributes to the measured values of capacitance and power factor as already described in earlier papers.[4,6] The increase of stress at the surface of separation of oil and paper is not yet high enough to cause breakdown of the oil. As the stress increases further the number of free ions in the oil increases rapidly, due to internal ionization. Thus, the volume of space charge increases and the local stress at the interface between oil and paper rises rapidly to values far above the overall average measured values, and initial gas formation and gaseous ionization occur, leading on to breakdown in a short time.

Pressure and Temperature

Over a wide range of pressure above and below atmospheric value, the volt-ampere characteristic of the oil is not affected in either position or shape. However, with decrease of pressure below atmospheric, breakdown occurs at lower and lower voltages and for very low pressures may take place in the saturation region of an oil of type (b). Increase of temperature causes an exponential increase of the value of the saturation current, and corresponding increases in the ordinates of the curve above the saturation region; the curve retains its shape but moves upward in exponential relation to the temperature increase. These relations are in accord with the theory of secondary ionization in liquids.[8] As related to the present problem, it may be noted that in a certain cable oil under constant value of stress, an increase in the temperature from 15 to 83 degrees centigrade causes the current to increase 40 times, and for a temperature of 102 degrees centigrade, 150 times. Increase of temperature decreases viscosity and increases ionic velocities and current. Up to about 50 degrees centigrade the product of conductivity and viscosity is approximately constant, indicating that the "free-ion content" of the oil is constant.[11] At higher temperatures further dissociation sets in with large increases in the number of free ions, current, and loss.

Ionization, Space Charge, and Power Factor

The normal power factor–stress curves[3] of Figure 9 may be explained somewhat as follows: The in-phase component of the current is due principally to the motion of ionic charges through the mass of the oil, and this motion causes an energy loss due to friction. The magnitudes of current and loss are thus very sensitive to the number of ions present, to their specific velocities (mobilities), and to the applied stress. In the initial or low-stress regions of the curves the first stirrings of oscillatory motion of the sluggish ions begins. With increasing stress excursions are longer, more ions begin to move, and the ionic current increases faster than the capacitance-charging current; the power factor rises. With increase of temperature, the same sequence occurs, but the power factor rises more rapidly and to higher values due to the thermal increase in the number of dissociated ions.

In the lower range of temperatures and for stresses between say 30 and 300 volts per mil the power factor–stress curves are flat. This is the region in which all of the liquid ions have been set in motion. Their excursions (with frictional loss) are unrestricted, and like the charging component of the current, are proportional to the stress; the power factor remains constant. These conditions obtain over the range 20 to 50 or 60 degrees centigrade, though the constant value of power factor increases with the temperature owing to the increase in the number of free ions.

With further increase of temperature the power factor maxima at low stresses appear. The increasing maxima are due to the thermal increase in the number of dissociated free ions. But the increase of temperature also causes a decrease in viscosity; ionic mobilities increase, and with increasing stress ionic oscillations reach the paper barriers of the oil spaces. Thus ionic motion is restricted, the loss component of current no longer increases linearly with stress; the capacitance component maintains its linear increase; the power factor decreases with increasing stress.

At stresses beyond say 300 volts per mil all these curves again enter regions of power factor increase at first gradual and then more rapid. This increase is caused by the rise in conductivity of the oil due to ionization by collision attendant upon the increase of stress. Ultimately these increases lead on to breakdown, space charge playing its part in increasing the internal oil stress as described above.

Original differences in oil power factor are also reflected in the constant-power-factor values of the impregnated insulation; but a lower oil power factor does not necessarily lead to a higher breakdown strength. Oil power factor is usually measured at low stress (say 25 volts per mil), and is due to the original free ion content and conductance of the oil. In the higher range of stress toward breakdown, however, the conductance of the oil is enormously increased by secondary ionization, rising to hundreds or even thousands of times the low stress value. The original difference is negligible in the greatly increased values of each. Aside from certain inherent properties of the oil itself, breakdown is largely dependent on space charge formation, in its turn related to the total number of mobile ions present. Consequently, it is not normal to find any correlation in oils between power factor and dielectric strength.

Breakdown

In the light of the foregoing the process of failure in the insulation here studied is readily explained as follows.

The original state of the insulation comprises thoroughly impregnated paper and completely filled oil channels, that is, entire absence of visible gas pockets or bubbles. The type then is that of the best oil-filled cable insulation.

Under increasing stress the first disturbance of the original condition is the liberation of small gas bubbles in the oil channels. This occurs when the crest

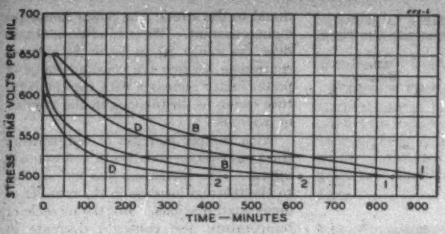

Figure 6. Variation of life and time to start ionization

Papers *B* and *D* impregnated with oil 5317

1—Life

2—Time to start ionization

value of the a-c stress wave reaches the breakdown (electron avalanche, or disruptive spark) stress of the oil. The computed value of the stress in the oil channels at final failure of the specimen in the paper density studies is from 1,000 to 1,500 volts per mil. The maximum disruptive strength of the purest hydrocarbon liquids is about 3,000 volts per mil,[3] that of a good cable oil substantially lower. The difference between these figures and those computed is to be found in the free ion content of the oil after impregnation, and, more important, in the consequent increase in stress near the paper surface by the accumulation of space charges in each half cycle.

Initial or crest gaseous ionization may not be detected at once on the recorder unless it occurs in a large number of places at the same initial critical stress. Nor does it necessarily result in a permanent gas bubble, if the stress rises no further. A minute gas bubble at the crest of the wave readily might be absorbed by the oil in the following half cycle during which the stress is below the critical value. However, if even crest ionization is allowed to continue it will liberate at each recurrence more liquid ions, the volume of the bubble and its attendant gas discharge will increase, attack the paper, and finally lead on to failure, with corresponding indications on the ionization recorder. Evidence of these conditions is found in the examination of several specimens removed from test at various stages of internal ionization. In these there was no gas formation or other evidence of approaching failure except a slight odor of burnt oil. However, on oil extraction and magenta staining clear wax deposits were found in every case, usually along the paper edges.

Some of the tests clearly indicate that for stresses as low as 400 volts per mil sufficient time will lead to the appearance of ionization and ultimately to breakdown. Figures 5 and 6 show that a time element is involved both before and after copious ionization begins. An explanation of the time element in the preionization (recorder reading zero) period is offered in the foregoing paragraph. In the postionization period time is obviously necessary for the gaseous discharge to burn its way through the adjacent paper tapes. Figure 3 gives a good idea of the growth of ionization in the average case; from post-mortem examinations of a number of specimens it appears that the central constant values of these curves is maintained while the ionization discharge is working through from one to three layers of the 16 layer specimen; from then on the failure proceeds with a rush. Obviously, as the rapidly applied stress is increased the time interval before ionization becomes shorter and finally disappears (in this work at from 600 to 700 volts per mil). Still further increase of stress reduces the time during which sustained ionization is evident. The shortest such time intervals observed in these tests were from three to nine minutes, at 700 volts per mil.

The Influence of Paper Density on Breakdown

The decrease in breakdown strength with increasing paper density found in these and preceding tests clearly is due to the increase of stress shifted to the oil channels by the increase in the dielectric constant of the denser papers. This and other behavior in the matters of conductance, capacitance, power factor, loss, and oil density have been explained in preceding papers, with particular reliance on the variation of ionic content and space-charge phenomena in oils.

The present tests, with increasing single values of stress rapidly applied and with failures occurring after intervals down to three minutes after the application of stress, show the same decrease in breakdown stress with increasing paper density as found in the earlier voltage step tests, which ranged over life values from two to four days. No attempt was made to shorten the life further by stresses above

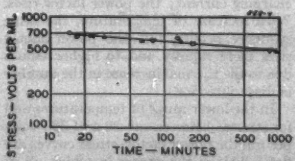

Figure 7. Life versus stress for four combinations of oil and paper

O—Paper *B*, oil 5314 Δ—Paper *B*, oil 5317

□—Paper *D*, oil 5314 ▽—Paper *D*, oil 5317

700 volts per mil. It should also be noted that for both oils, stresses for immediate ionization are more than 12 per cent higher for the lighter than for the heavier paper.

As to tests of impulse type, that is, durations of stress of the order of microseconds, the time intervals requisite for ionization to begin and to increase disappear, and breakdown takes on the character of disruptive discharge or so-called pure electric breakdown. If the medium is uniform this type of breakdown should occur at higher stress the denser the medium, as based on theory and confirmed by experiment. Cable insulation is not uniform, and the mechanism of failure pictured in these studies makes it a matter of progressive action first in the oil and then in the paper. Under impulse test the influence of time is practically excluded, and it may well be that the over-all density is the controlling factor. The results of Foust and Scott[4] give some support to this view; and as already noted Figure 6 suggests that for the heavier oil the curves for *B* and *D* paper may coincide or cross each other at still higher stresses.

There remains the question of the apparent contradiction between these studies and cable manufacturers' informal reports that the use of high-density paper results in higher dielectric strength. A possible answer suggests itself as follows.

If the comparison is that between a cable insulated completely with low-density paper and the same cable insulated completely with high-density paper, then the present studies indicate strongly that the former would have the higher dielectric strength in tests such as here reported, excepting possibly those of impulse types. However, if the cable-conductor insulation is made up in part with high-density paper next to the conductor, and in part with low-density paper outside, two conflicting conditions enter as follows:

(*a*). The electric stress at the surface of the conductor is reduced due to the increased capacitance of the inside-high density paper.

(*b*). The ratio of the dielectric constants of the denser paper and of the oil is increased, and so tends to increase the stress in the oil channel, and thus offset the lowering of stress of condition (*a*).

Approximate analysis in terms of cable dimensions and dielectric constants leads to equations which show that under certain conditions, for the same dimensions and the same value of applied voltage, the value of the oil stress in the channels of the inside high-density paper, may fall below that in the inside oil channels of the same specimen insulated throughout with low-density paper. Thus for a single conductor with cable insulation compounded of high- and low-density papers, a gain of dielectric strength up to 11 per cent over that of the low-density paper

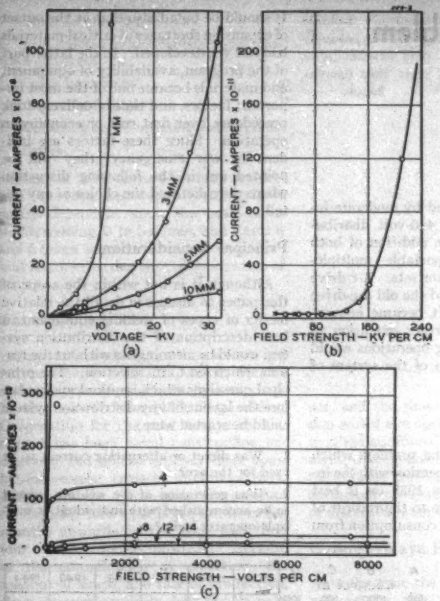

Figure 8. Current–voltage curves in insulating oils

(a). Commercial insulating oils
(b). Further purified
(c). Successive distillations

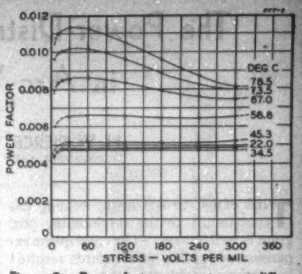

Figure 9. Power factor versus stress at different temperatures

alone is indicated, depending on the dimensions and relative values of paper density and dielectric constants of paper and of oil.

Gas-Filled Cables

It is interesting to ask whether these results have any bearing on the conditions in gas-filled cables. There being no free oil in the channels it appears that the mechanism of a short-time test failure may be of different type; space-charge and surface-layer effects are probably lower in value and of less effect; the cumulative oil ionization leading to failures at lower stresses and longer times in oil-filled channels has no obvious counterpart in gas-filled insulation. On the other hand two important facts stand out:

1. The ratio of values of stress in paper and oil noted are more than doubled for the paper and gas of the gas-filled cable.

2. Local ionization in gas-filled insulation may not be reflected in an over-all measurement of power factor of even a short sample, and such local ionization once started must be a serious menace even to wax-covered paper.

It would be interesting to know the values of stress at which local ionization, as distinct from that indicated by power-factor curves may first be detected in gas-filled insulation, and its rate of growth if any, as a factor in ultimate failure.

Conclusions

1. High-stress short-time constant-temperature tests of completely impregnated cable-paper insulation, approximating that in oil-filled cables, show that a higher-density paper has a lower breakdown strength. The results confirm those of earlier tests in which a step-voltage test over longer times was used. The behavior is much the same for both a light and a heavy oil.

2. A method is described for detecting the first occurrence of gaseous ionization in impregnated-paper insulation and for taking a continuous record of its growth up to breakdown. Interruptions of the tests at various stages as revealed by the ionization recorder show that ionization and failure almost invariably begin in the oil channels of cable insulation, and that a time element enters in both preionization and subsequent ionization periods.

3. Breakdown stress–time curves have been plotted for low- and high-density papers, each impregnated with a light and a heavy oil, for stresses between 700 and 500 volts per mil, and corresponding time intervals between 3 minutes and 900 minutes. A time variation as the inverse 12th power of the stress is suggested.

4. The mechanism of breakdown and power-factor and capacitance variation as related to paper density are discussed and explained in terms of fundamental conductance phenomena in insulating oils.

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The Power-Distribution Problem in Arc Welding

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THE extent to which arc welding has contributed to the shipbuilding program is well known. The consequent expansion of welding in shipyards resulted in various problems: the training of operators, production of the materials used, and by no means least, the development of satisfactory power-distribution systems. It is the intent of this paper to discuss briefly the general principles of power distribution for arc welding and to illustrate the application of these principles in the provision of an adequate, flexible, and economical distribution system in a typical shipyard. Although many conditions in shipbuilding are peculiar to the industry, it is believed that similar reasoning can be applied to any metal-fabricating plant making use of arc welding on a like scale.

Background

In the period between World War I and World War II, the plant of the New York Shipbuilding Corporation consisted essentially of five large covered building ways, a wet slip, outfitting piers, and the usual shipyard fabricating and outfitting shops. The corporation had commenced building operations in 1900 and therefore had a background of long experience in riveted ships of all classes. Arc welding was introduced in the yard prior to World War I on a very small scale; as late as 1930 equipment for this work consisted of only a score of individual d-c motor-generator sets and one constant-potential multiple-operator set with half a dozen outlet panels. Power for most of the welding machines and other power applications was provided by a 2,300-volt distribution system supplying various substations, transforming to 440-volt three-phase 60-cycle power for the shipways and fabricating shops. Some use was made of d-c power distribution in the case of the latter.

Applications of arc welding increased steadily from 1930 to 1939, particularly in the naval vessels then building, and the number of operators employed reached a peak of 300. Power for these growing operations was provided by moderate increase in the regular 440-volt distribution system, and some addition of both single-operator and portable multiple-operator motor-generator sets. A-c drive was made standard, and the old d-c-drive sets were replaced. It became increasingly evident that further extension of welding in shipbuilding operations would require radical revision of the system of power distribution.

Expansion

The magnitude of the problem which had to be solved in connection with the increase of activity from 1939 on is best understood by reference to the records of employment and power consumption from that time to the present. The power consumption and demand curves shown in Figure 1 are, of course, for all power used in the yard, as it is not possible to separate that used for welding operations except in certain areas. Records at these points established the correlation between electrode consumption and power, and these, when applied to the yard as a whole, indicate that at the peak in 1943 arc welding accounted for at least 1,250,000 kilowatt-hours per month.

In 1939, moreover, the contracts under negotiation only partially indicated the requirements of the future, but it was realized that a basic plan of distribution would have to be selected which would be highly flexible and which could be expanded as increased demands were placed upon it. At no time during this expansion period was it possible to predict the welding requirements with any degree of accuracy for more than the next 12 months. It should be noted also that at the outset of expansion shortages of critical materials had not yet developed. In the latter part of the program, availability of equipment and materials became one of the most important factors, and time of delivery took precedence over first cost or economy in operation. Since these factors are incident to war emergency, they will be pointed out in the following discussion where they dictated the choice of any detail.

	A	B	C	D
		MULTIPLY BY		
	100	1000	100	100
	320	10,200	234	60
A—Total man-load	245	8,200	194	50
B—Kilowatt-hours monthly	170	6,200	154	40
C—Maximum demand				
D—Welding man-load	95	4,200	114	30
	20	2,200	74	20
		200	34	10
				0

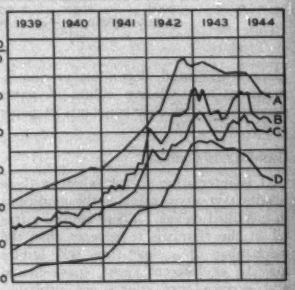

Figure 1. Power and man-load record, New York Shipbuilding Corporation, 1939–44

Principal Considerations

Although it is not within the scope of this paper to discuss in detail the relative merits of types of welding equipment, a bare description of the distribution system would be meaningless without the reasons which led to its selection. The principal questions which required answer before the layout of any distribution system could be started were:

1. Was direct or alternating current to be used for the arc?
2. Was generation of d-c welding current to be accomplished with individual or multiple-operator units?
3. What was the maximum current and range of current to be supplied each operator?
4. What was the total power to be delivered to each specified area of operation?

The first two items are highly controversial; furthermore, technological improvements present a constantly changing picture. Decision can be made only on the basis of close examination of all factors involved in a specific application.

Primary Factors

The selection of equipment and, therefore, the determination of the main features of the distribution system rest with the following factors:

1. Position in which welding is done.
2. Size and types of electrodes used.
3. Average current demand per operator.

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4. Total number of operators.
5. Area covered by welding operations; distances involved.
6. Space limitations.
7. Cost of installation.
8. Operating costs, including maintenance.
9. Safety.

Many of these factors are interdependent: the size and type of electrode is partly dependent upon the position in which welding is to be done, and items 4 and 5 taken together form a most important factor—the degree of concentration of force.

General Conditions

Shipyards and shipyard practices are not necessarily alike, depending on the size and type of ship built by any yard. In the case of New York Shipbuilding Corporation for the past five years, the output has been naval construction exclusively and almost entirely large combatant vessels: cruisers, aircraft carriers, and battleships. Even under the pressure of wartime, such vessels require from ten months upwards on the ways and from four to eight months outfitting. Because of the complication of structure, the amount of shape, and rate of production, there is comparatively less opportunity for subdivision of the work, and, consequently, the necessity to do a high proportion of welding on the ways. The welding force increases with the steel erected, reaching a maximum at launching. It then drops to zero until the next keel is laid down, when the cycle starts over again.

Following launching, the ship moves into the wet slip where heavy weights, such as turrets, are installed and finally to an outfitting pier for completion. The welding load drops only momentarily following launching and, as a rule, equals or frequently exceeds previous peaks during the outfitting period, decreasing sharply as the delivery date approaches.

Welding conditions in the shops are quite different from those in the wet slip, and there is considerable variation between shops, depending upon functions. Insofar as welding operations are concerned, we deal principally with the plate and angle, boiler, copper, pipe, machine, and turret shops. The subassembly areas or slabs are quite similar to the plate- and angle-fabricating shop, in regard to welding.

In illustrating the application of factors which led to the choice of the distribution system, it is therefore convenient to deal with the ways, the outfitting piers, and the shops separately.

As previously noted, the entire system developed over a period of several years. The first step was the provision of adequate power on the five permanent and covered ways, the wet slip, piers then in use, and the shops. Subsequent expansion added five open temporary ways and required additional pier facilities. In the main, this expansion was an extension of the systems previously adopted, but some additional problems, notably availability of materials, were involved.

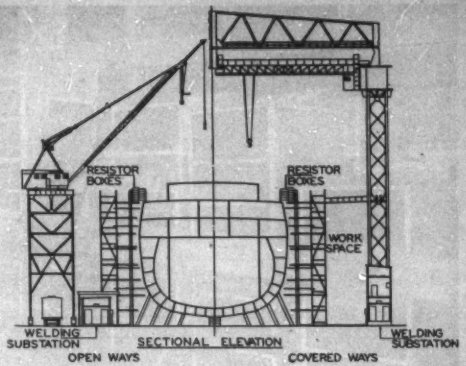


Figure 2. Sectional elevation of building ways, showing both covered and open types

Covered-Ways Equipment

At the time the power system was developed for this area, there was little choice in the type of power for welding. A large percentage of the welding must be done in the vertical and overhead positions, and electrodes for alternating current, which would operate as easily and give comparable speeds and weld quality, were not available. Even now, with great improvement in a-c electrodes, the use of alternating current for ship work on the ways is debatable. It is necessary to have moderately long lines from the machine or panel to the work. This line lies on and across great masses of steel and leads through openings and hatchways, resulting in large and variable inductive drops. Although alternating current has been used on the ways in a number of European shipyards, direct current is almost always used in the United States.

The relative advantages and disadvantages of the two methods of generating the d-c power, the single-operator or the constant-potential multiple-operator set, require more consideration. Both types were available, both had been in use in this yard. The peak load on one shift on one way was estimated at 120 production operators and 80 tackers, therefore, requiring some 200 welding machines or panels per ship during the last months on the ways. This represents a high concentration of force. Space in the way area is at a premium, even if the machines or panels could be located at ground level. The length of welding cable actually handled by each operator had been standardized at 200 feet, made up of 100 feet of 2/0 cable attached to machine or panel, and 100 feet of 1/0, permanently spliced. This represented a compromise between minimum voltage drop and a length which would permit a reasonable working radius with minimum weight. Reference to a sketch showing a typical sectional elevation of the ways, Figure 2, shows the necessity, even with a 200-foot lead, for keeping the current control as close to the ship and to the level of the top deck as possible. This may be done by locating the machines either on deck or in the staging. The former method is very unsatisfactory on ships with a number of decks or much subdivision, since all machines have to be moved as additional steel is erected. Even when a group of machines is nested in a cradle there is still interference and loss of valuable deck space. The use of the staging space is a far better solution. One or two vertical moves keeps the outlet close enough to the top of structure yet is relatively independent of erection. Leads are very little longer than when placed on deck and there is no interference with cranes or other services.

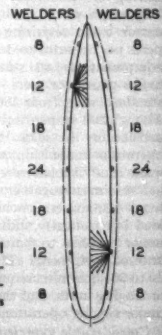


Figure 3. Typical resistor-box grouping of panels to provide 200 operators per ship

It is our usual practice to group machines or outlets at stations along the

Figure 4. Front view of stack of resistor panels for ship welding

Figure 5. Rear view of stack of resistor panels for ship welding

ship's side, spacing these groups at intervals so that the effective working radii of leads overlap, thereby affording coverage for all jobs. Since the bulk of work is amidship, the grouping at these points is heavy and, in a typical case, takes the form shown in Figure 3.

Most ship welding on the ways is done with electrodes of $^{3}/_{16}$-inch or less diameter, using less than 200 amperes, due to the fact that so much welding is done in either the vertical or overhead positions. Tack welding requires much less, besides having an extremely low duty factor. There is, however, enough heavy deck and armor work requiring 300 to 400 amperes per operator to demand some heavy equipment at all stations. Individual motor-generator sets are available in standard sizes from 100 to 600 amperes. Though 200-ampere units have been found satisfactory in some cases, the 24-hour operation under shipyard conditions has made it advisable to use 300-ampere units as a minimum together with a lesser number of 400-ampere machines. As the work load is constantly shifting, it becomes a major problem to maintain a proper balance of equipment. The weight of some 20 to 30 such units requires special towers or staging units, and their movement is a major rigging operation.

Considerable experience with constant-potential motor-generator sets in the past had established, to our satisfaction, the following points:

1. A 1,500-ampere constant-potential set would carry 15 operators and ten tack welders on this type of work.

2. Parallel operation of such machines increased the number of production operators which could be carried to 120 when six units were in parallel.

3. At these loads, interference was nil or negligible.

4. Reactors were unnecessary to stabilize the welding circuit.

This led the way to our own design of a very compact and lightweight resistor panel, providing 30 to 200 amperes, in steps of ten amperes, independently, for each of two operators. In jobs requiring more than 200 amperes, a paralleling

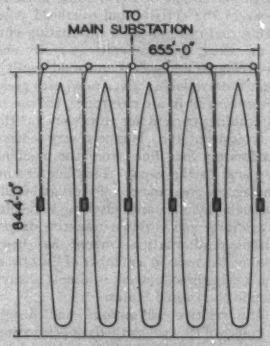


Figure 6. Plan of ways showing location of substations

■—Welding substation
O—Underground manhole
·-·-·—Duct system
—·— 2,300-volt feeder

switch could be closed, permitting only one welder to work but giving 60 to 400 amperes. The total weight of this double-outlet panel is 180 pounds against 872 pounds for two standard 200-ampere individual units or 1,700 pounds for two 300-ampere units. The double panel is designed for stacking as shown by Figures 4 and 5, and the total weight of a group of 12 panels or 24 outlets is, therefore, only 2,160 pounds. Due to this light weight, it is possible to place these stacks on ordinary staging, which means being able to place them in the most desirable location and to shift them easily as conditions change.

These considerations alone would have lead to the adoption of the constant-potential system for way's work. First cost was, as a matter of fact, lower for the entire system, and, from a safety standpoint, all portable cable and connections were thus handling 70 volts maximum instead of 440 volts. From a maintenance standpoint, oiling and upkeep of some 200 small motor-generator units would prove considerably more costly than would the six large units favorably located in a substation. A temporary-light station is placed adjacent to the substation, and the man in charge of temporary lights and service at that point is the operator of the welding substation, starting and cutting in machines as required. Since the panels are of simple and rugged construction, they withstand misuse and rough handling to a surprising degree.

There was, in this case, no disadvantage in the fact that all machines must work on the same polarity. The electrodes used for medium-steel structure, as well as the chrome-nickel austenitic electrodes, all either were designed for d-c reverse polarity or operated satisfactorily on either polarity.

Power Distribution on Covered Ways

The estimated man load per shift per ship was 120 production welders averaging 180 amperes per arc with an esti-

mated operating time of 30 per cent, requiring, therefore, a capacity of approximately 7,000 amperes per way. The largest standard motor-generator set available was the 1,500-ampere size rated at 1,200 amperes continuous or 1,500 amperes for one hour. Six machines would, therefore, carry the estimated load. As previously stated, this had been checked by experience, and it was found that the 60 to 80 tack welders required per ship per shift also could be carried without overloading, because of the extremely low operating time required in tacking.

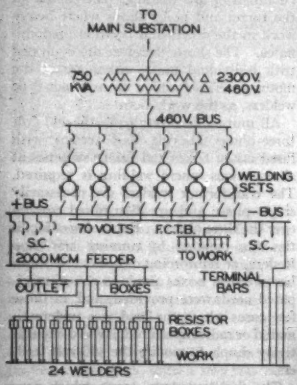


Figure 7. Single-line diagram of a typical welding substation and distribution to operators

F.C.T.B.—Full-capacity terminal bar
S.C.—Similar circuits

It is common practice to locate welding substations of this nature at the head of the ways. In this case, such space was not available, and, secondly, due to the length of the ways, it appeared highly desirable to locate the machines at approximately mid-length to reduce line drop and the amount of copper required. Accordingly, six welding substations were installed as shown in Figure 6. A single-line diagram of typical welding substation is shown in Figure 7. Under the covered ways, due to the column arrangements supporting the crane ways and roof, an area of 10 by 30 feet was available at each location.

On account of this small space a two level substation was designed, the upper level housing the switchgear and transformers, the lower level housing six constant-potential welding machines (Figure 2). To co-operate with the manufacturer, it was decided to mount the control equipment for both motor and generator above the motor-generator set, all supported on a common base, thus shortening the set and giving a very compact unit. A 440-volt driving motor was selected because of the use of 440-volt supply for miscellaneous power in ship construction and also because control equipment would be much smaller and less expensive than with 2,300 volts. From the standpoint of portability, such sets then could be used throughout the yard.

Synchronous motors on other power application had accomplished satisfactory correction of the yard power factor; therefore, induction motors were chosen for welding, again resulting in lower cost. The final machine adopted consisted of a 440-volt, 150-horsepower induction motor driving a 1,500-ampere 70-volt generator with an over-all length of 7½ feet. This size permitted six machines to be located in the space assigned, giving a total capacity of 9,000 amperes for one hour or 7,200 amperes continuously, which was safely above the estimated load. A typical interior view is shown in Figure 8.

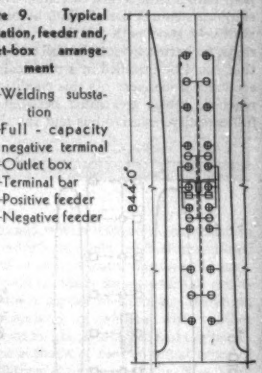
The machine described made a compact portable unit permitting a ready transfer of machines between stations as the work load built up on a particular way, thereby eliminating the possibility of idle machines and greatly reducing the number required.

From the main substation, where switchgear with adequate short-time and interrupting capacities could be provided, a 2,300-volt cable was installed to each

Figure 8. Interior lower level of typical six-machine substation

welding substation, directly connected to a 750-kva bank of air-cooled transformers stepping down to 440 volts. Air-cooled rather than oil-cooled transformers were selected because of fire hazard adjacent to the ships under construction. Each motor circuit was connected to the 440-volt bus through air circuit breakers to the welder motor below. The generators are paralleled through a ring bus with positive and negative feeders taken off at opposite ends of their respective rings. This places all units equidistant from point of take-off and insures equal distribution of load between machines. This is of great importance, when it is considered that the load reaches a maximum of 9,000 amperes, and, in one station where ten machines are used, it reaches a maximum of 15,000 amperes. From the positive bus four 2,000,000-circular-mil feeders are connected through 2,000-ampere single-pole air circuit breakers, the feeders running parallel to the shipways. These feeders branch out, two in each direction, overlapping at the midship area or in heavy-load center (see Figure 9). Connected to these feeders are 18 outlet boxes spaced along each side of the shipways to give flexibility and to shorten the portable

Figure 9. Typical substation, feeder and, outlet-box arrangement



cables connected to the resistor boxes shown in Figures 3, 4, and 5.

This is the end of the permanent installation. To these outlet boxes there are connected four portable cables which run to the ship where 12 200- to 400-ampere duplex resistor panels are connected supplying a total of 24 welders.

Tack welders, who use small electrodes and comparatively low currents, could use a much smaller panel. Special tacker's panels are, in fact, in use in some yards. We have not adopted this for various reasons. It is common to have the heaviest tacking force on the day shift, working with other crafts in the erection and fitting of structure. Succeeding shifts carry a higher proportion of welders who perform the production work. When tackers finish, their lines are left on the job, and are taken over by the welding operator, with consequent saving of time and effort. To conserve on the number of panel outlets where an unusually large force of tackers is assigned to a shift, we have found it practicable to work two on a single outlet. The duty cycle is so low that there is little interference between the two, even when they are not in the same vicinity or in direct communication.

Particular attention is paid to the ground or return system. From the negative bus or ground return there are connected four 2,000,000-circular-mil cables each terminating at four equidistant points

along the shipways. At these points there are heavy copper terminal bars to which the hulls of the ships are well bonded with portable cables. In addition there is installed a full-capacity negative ground terminal connected directly to the generator bus located amidship, or in the heavy-load center, to which the ships' hulls are connected with portable cables. These also are shown in Figure 7. In the early stages of ship construction the four feeders are necessary because various joints, seams, and so forth of the hull have not been completed, which offers a poor path for the return currents. As the ship nears completion the hull becomes a relatively good path for the return currents, far better, in fact, than all the cables that could be installed in a practical and economical manner. As this condition is reached, cables are added between the full-capacity negative bus and the ship's

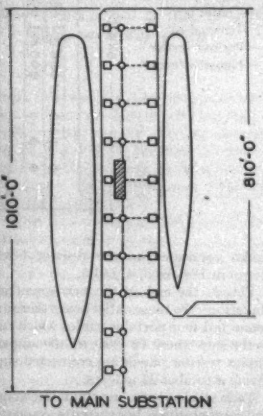


Figure 10. Welding substation and distribution system on typical outfitting pier

■—Welding substation
○—Underground manhole
□—Outlet box
– · –—Duct system
– – –—Conduit system

hull, until practically all the return currents are returning to the substation at this point.

Outfitting Piers

Insofar as the selection of welding equipment for the outfitting piers is concerned the factors are very similar to those considered for the covered ways. The outfitting piers are long and narrow with gantry cranes spanning practically the entire width. Thus, very little space was available between the crane rails and the side of the pier for location of welding equipment. As on the ways, consideration of space and weight requirements led to the adoption of the constant-potential system with, however, provision of sufficient power for a few individual-operator machines to cover any special job in the course of outfitting which might require a different polarity or special equipment.

A welding substation was installed between the crane tracks spanned by the gantry cranes. From the substation's cable vault an underground-duct system was installed to outlet boxes located on each side above ground between the crane rails and the sides of the piers, as shown in Figure 10. These outlet boxes are connected to the underground manholes with metallic conduits running under the crane rails. The resistor boxes are stacked in groups on the decks of the ships and are connected by portable cables to the outlet boxes (see Figure 11). With this method no interference was experienced among the cranes, material handling, ship mooring cables, and the welding outlet boxes and cables.

On the outfitting pier, where ships are moored one on each side after launching, an extremely heavy welding area was created. Based on an estimated man-load peak of 160 welders per ship with two large ships outfitting simultaneously, or 320 welders per shift, using 150 amperes per man with an operating time of 25 per cent, a capacity of 12,000 amperes was required.

The same type and size of multiple-welding machines are used as on the ways for interchangeability between stations. A ten-machine station was installed having a total capacity of 15,000 amperes one hour or 12,000 amperes continuous. The one-hour rating takes care of all additional power required for tacking service. The ten welding generators were paralleled on a ring bus with the positive and negative cables taken off at opposite ends of their respective rings. From the positive ring ten 2,000,000-circular-mil insulated feeder cables were connected through ten 2,000-ampere single-pole air circuit breakers, these cables running underground through the duct system to 20 outlet boxes (two boxes per cable). From the negative ring ten 2,000,000-circular-mil bare cables were installed, these cables running underground through the duct system to the same outlet boxes. This shipyard is located in a fresh-water area, and, with the ship well-bonded to heavy negative-ground return cables, no pitting of ships' hulls due to electrolytic corrosion has been experienced.

Shops

Welding conditions in most of the fabricating shops are very different from those discussed under ways and outfitting piers. The operators are either in relatively small groups or are widely distributed over a considerable area, so that the concentration of force is low. More positioning for downhand welding is done, hence the average current used is much higher. Many shop operations require special electrodes, and more or less frequent changes in polarity are necessary. Space is usually ample for locating machines, and, as work loads are uniform and steady, there is little occasion to move or transfer equipment. An individual machine can, therefore, be selected which can be used to capacity and which is particularly suited to the operation at that point, whereas the multiple-operator set is at a serious disadvantage.

In many instances full advantage can be taken of a-c welding, particularly in the turret and boiler shops where heavy work in the downhand position predominates. The shops therefore are equipped with individual units, either a-c or d-c motor-generator sets or transformer-type welders, as the work dictates.

All units take power from the 440-volt three-phase 60-cycle shop feeders with fused outlet boxes and safety switches at all locations where welding is required. The transformer welders are necessarily single phase and are distributed equally over the three phases. Expansion of facilities was handled by running new shop feeders, or reinforcing old ones. A number of outlet boxes ample to cover anticipated needs were provided, and, in those few cases where the load was underestimated or radically shifted, it was comparatively simple to modify the 440-volt feeders.

The five temporary ways, which concluded the expansion problem, presented a similar electrical problem to that on the permanent covered ways, except that the former were intended for slightly smaller ships, and there was no overhead crane structure, as shown in left-hand side of Figure 2. These ways were built on the site previously occupied by two wide ways in World War I. This resulted in an arrangement permitting a very narrow space between pairs of ships and prevented installation of machines or outlets between each ship. On the other hand, this close coupling permitted a ship to be serviced for welding entirely from one side, assuming adequate generating capacity.

Three six-machine substations were, therefore, installed for the five ways (Figure 12), the compact design permitting the station to be located between the ship and the gantry space and actually under the staging. Since length was not restricted, but height had to be kept down the machines, transformers, and switchgear were all located on the same level with an underground-duct system branching out from each substation to the various outlet boxes located on both sides of the pairs of ways. All cables were run underground to the outlet boxes with portable cables connecting these boxes to the resistor units located on the staging at the side of the ship.

The estimated welding man-load per ship

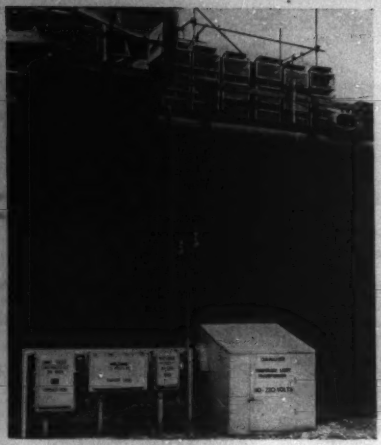


Figure 11 (left). View of power-distribution outlets on pier with welding resistor panels on ship

Figure 13 (right). Arrangement of single-operator welding machines for shipways use

per shift was 90 welders using 180 amperes per arc with an operating time of 30 per cent. This meant a peak load of approximately 4,860 amperes. The fact that two adjacent ships would not be expected to be in the same construction stage at the same time allowed sufficient margin whereby two ships could be supplied from a six-machine station. This condition proved satisfactory, until a ship was held up due to change in design. This caused a welding peak to develop beyond the capacity of the substations.

Normally, an additional substation would have been installed on the open side of the fifth ship to supply the additional welding capacity. As it was impossible to obtain either the large constant-potential motor-generator sets or the transformers and switchgear in time, it was necessary to use items on hand. Eighty 200-ampere individual motor-generator sets were found to be immediately available; accordingly, five towers were installed on the side of the ship way and five 440-volt circuits were run, one to each tower, from existing 440-volt outlets in the vicinity. These also are shown on Figure 12. Sixteen welding machines were located on a platform on each tower permitting the 16 machines to be lifted as a unit as erection progressed on the ship. See Figure 13. A standard welder's lead was run from each machine to the working locations on the ship. The negative or ground-return cables were connected to a heavy bus bar which was mounted on each tower and bonded to the hull of the ship.

It is interesting to note that the system used at this particular way was one of the alternatives considered and discarded in deciding the principal power-distribution system for welding on the ways. Experience with the system wholly justified the original decision where time of delivery

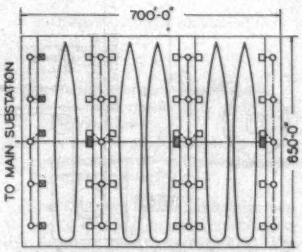


Figure 12. Plan of open ways showing location of substations and distribution system

▥—Welding substation
o—Underground manhole
□-·-·-Duct system
– – –Conduit system
⊠—Tower for single-operator welding sets

or a lack of critical materials did not apply. Although some of the difficulties encountered were due to the fact that 200-ampere machines rather than 300-ampere machines had to be used, the lack of flexibility and portability in this emergency setup was keenly felt. Both operators and supervisors in welding, as well as other departments affected, are in unanimous agreement on this point.

Incidental Power

In conclusion, there remain substantial power demands for items incidental to, but not included in the foregoing discussion of welding power. Electric arc welding releases various fumes and gases, which have been proved low in toxicity but which are irritating and, like all metal fumes and smoke, dangerous, if inhaled in concentrations easily reached in confined spaces in ship's compartments and tanks. Removal of these fumes and the provision for a supply of fresh air, therefore, are problems of welding and another problem for the plant electrical engineer.

Use is made of two principal types of ventilating equipment at the New York Shipbuilding Corporation:

(*a*). A two-horsepower individual exhauster, handled by the welding operator and taking the fumes directly from the arc, designed for use on the 240-volt 180-cycle system provided primarily for drilling and reaming operations aboard ship and in the shops.

(*b*). Fifteen-horsepower exhausters with multiple 4-inch suction lines which can be led to various working locations, exhausting fumes outside the ship.

These operate from the 440-volt, three-phase 60-cycle system provided for general power. The extent to which ventilating apparatus for welding increases the power requirements can be appreciated, when it is compared to the power actually consumed in welding operations. Depending upon the degree to which the ship has been closed in, the concentration of work, and many other factors, from one-third to one-half as much power may be used in ventilation as in actual welding.

The use of welding in fabricating extremely heavy sections as in stern posts, rudder crossheads, and in joining high tensile and ballistic steels with moderate to high hardenability, has added the necessity of extensive preheating. Though this can be accomplished in some instances in a furnace, as by gas or oil torch, electric preheating is by far the most satisfactory form for most applications. Both induction and resistance types are in use, but

Induction Heating of Moving Magnetic Strip

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Synopsis: The general problem of heating iron or steel strip by induction is analyzed to arrive at equations for power-factor efficiency and density of heating under all conditions. Certain general curves are shown to illustrate the limitations of strip thickness, frequency, and density of heating.

MANY engineers are already familiar with the application of radio-frequency power to the brightening of electrolytic tin plate in continuous-line production. In this process, induction heating raises the temperature of the iron strip to the melting point of tin, causing the tin surface to melt and flow into a uniform tightly adhering layer while the strip is traveling at speeds up to 1,000 feet per minute or more. This application required the use of vacuum-tube oscillator equipment (frequency about 200 kilocycles) because of the thinness of strip to be heated: (0.007 inch to 0.014 inch approximately). There are, however, many possible applications of induction heating to thicker iron or steel strip, which may be accomplished by rotating machines (inductor alternators) having an upper practical frequency of about 10,000 cycles per second (9,600 cycles standard). This paper is written to show when and how iron strip may be heated at machine frequencies (9,600 cycles) and to show when it is necessary to use higher frequencies supplied by industrial vacuum-tube oscillators or generators.

There is practically no limitation on the thickness of strip which can be heated by induction, but, since a continuous-line process is considered, the most likely thickness range is from 0.003 inch to 0.032 inch. Strip widths up to four or five feet can be satisfactorily handled.

This treatment is limited to iron or steel strip which is ferromagnetic. Paramagnetic materials like copper, aluminum, brass, and such cannot be heated satisfactorily by the usual process of induction heating. Iron and steel lose their ferromagnetism between 700 and 800 degrees centigrade and cannot be heated economically above this temperature.

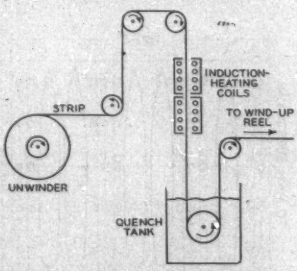

Figure 1. Simplified arrangement for induction heating of continuous moving strip

A much simplified handling and heating equipment is shown in Figure 1. The heating coils usually are wound in a single layer from hollow copper tubing about one-half-inch outside diameter and with the turns spaced one-eighth inch to one-half inch, depending on the frequency and the job to be done. The turns make complete loops around the strip and conform to the strip as closely as electrical and mechanical considerations permit. The coil may be made in several sections as indicated and extend from one foot to ten or more feet along the strip. Suitable support and insulation must, of course, be supplied.

Figure 2 shows typical circuits for feeding power to the work coil; circuit *a* using a vacuum-tube generator (200 kilocycles or higher) and circuit *b* using an inductor-type alternator (3,000 to 9,600 cycles).

Nomenclature

W_w = total watts required or induced in strip
N = strip speed (feet per minute)
c = specific heat
A_s = area of strip cross section (square centimeters)
θ = temperature rise of strip (degrees centigrade)
l_c = length of coil (centimeters)
μ = effective magnetic permeability of strip
H = peak magnetizing force (oersteds)
f = frequency (cycles per second)
t = strip thickness (centimeters)
K = a parameter (see equation 3)
ρ = electrical resistivity of strip (ohm centimeters)
$G(Kt)$ = a function of Kt (Figures 3 and 5)
W = watts per cubic centimeter in strip
K_1 = a constant (see equation 5)
B = flux density corresponding to magnetizing force, H; for H greater than 60, B = 18,000 gauss
I = coil current (rms) amperes
V = coil voltage (rms) volts
n = turns per centimeter in coil
W_c = copper loss in coil (watts)
b_c = width of coil (centimeters)
b_s = width of strip (centimeters)
h_c = smaller dimension of coil opening (centimeters)
K_L = voltage factor of coil
$(VI)_a$ = coil volt-amperes due to flux in the air
$(VI)_i$ = coil volt-amperes due to flux in the iron
b_f = depth of flux penetration (centimeters)

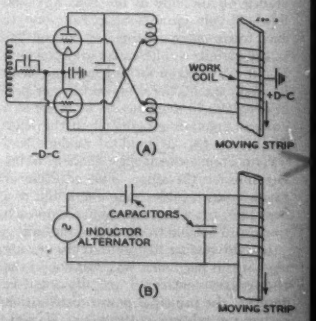

Figure 2. Electric circuits for induction heating of moving strip

Paper 45-80, recommended by the AIEE committee on industrial power applications for presentation at the AIEE winter technical meeting, New York, N. Y., January 22-26, 1945. Manuscript submitted November 25, 1944; made available for printing December 26, 1944.

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preference here is toward the resistance method, using strip heaters attached to the work. Aboard ship the 440-volt power is stepped down to 115-volts through 37½-kva portable air-cooled transformers for ship-lighting circuits. Preheating makes use of this power, the strip heaters being connected up in very much the same manner as temporary lighting.

In the heavy fabricating shops, where preheating is an even heavier load, use was made of existing 230-volt d-c power feeders no longer needed for power tools, which had been converted in the course of several years, to a-c. Had such d-c power and shop feeders not been available, preheating in these shops would have been handled as aboard ship and would have required further reinforcement of the 440-volt shop feeders.

Power Required to Heat Moving Strip

The power required to heat strip depends on the weight of strip passed through the coil in unit time, its specific heat, and the temperature rise desired. It is expressed conveniently as

$$W_w = 16.6\, NcA_s\theta \text{ watts} \quad (1)$$

where

N = strip speed (feet per minute)
c = specific heat
A_s = cross section of strip (square centimeters)
θ = temperature rise (degrees centigrade)

The equation for the watts per cubic centimeter which must be generated in the strip for a given speed and temperature rise is

$$W = \frac{16.6N\theta}{l_c} \text{ watts per cubic centimeter} \quad (2)$$

l_c = length of coil (centimeters)

Power Generated in Strip

Because of the complications introduced by magnetic saturation, the mathematical problem of calculating the power

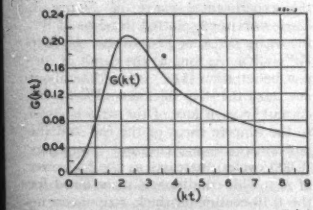

Figure 3. Strip heating by induction G(kt) versus (kt)

$$W = {}^1/_2\,\mu H^2 f G(kt) 10^{-7} \ \frac{\text{watts}}{(\text{cm})^2}$$

$$k = \sqrt{\frac{4\pi^2\mu f}{\rho}\,10^{-9}}$$

For large values of kt, $G(kt) = \frac{1}{2kt}$

input to a magnetic strip by a certain magnetizing force and frequency never has been accurately solved. The problem has been solved mathematically on the assumption that the permeability (μ) is constant in the strip and depends only on the peak magnetizing force at the surface. This solution gives

$$W = {}^1/_{2\mu} H f G(Kt) \times 10^{-7} \text{ watts per cubic centimeter} \quad (3)$$

where

μ = magnetic permeability
H = peak magnetizing force at the surface of the strip (oersteds)

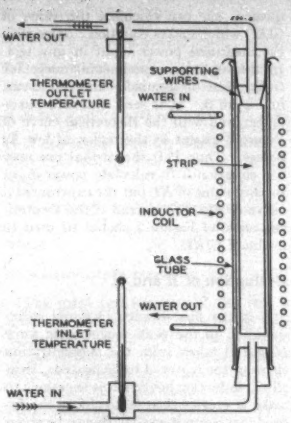

Figure 4. Schematic arrangement for measuring power input to strip

f = frequency (cycles per second)

$$K = \sqrt{\frac{4\pi^2 2\mu f 10^{-9}}{\rho}}$$

t = thickness of strip (centimeters)
ρ = electrical resistivity of strip (ohm centimeters)
$G(Kt)$ = a function of Kt, involving hyperbolic functions and plotted for convenient use in Figure 3

It can be shown for the nonferrous metals ($\mu = 1$) that $1/K$ is equal to the effective depth of current penetration. The same is approximately true for the ferromagnetic metals (iron and steel) below the Curie point (750 degrees centigrade), if (μ) is given the proper value.

For large values of Kt, corresponding to small depths of current penetration in

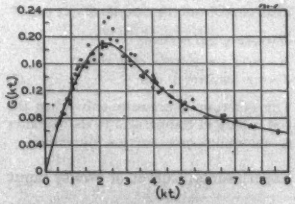

Figure 5. Experimental curve G(kt)

Summary of data for all strip thicknesses and all frequencies of tin plate

0.0095 inch—193 kilocycles
0.007 inch—77 kilocycles, 193 kilocycles
0.003 inch—77 kilocycles, 168 kilocycles, 300 kilocycles
0.00115 inch—88 kilocycles, 300 kilocycles, 490 kilocycles
9.6 kilocycles—0.32 inch, 0.028 inch, 0.005 inch, 0.007 inch

Table I. Power Factor and Efficiency at 9,600 Cycles

Five-Foot Active Coil Length

Strip Thickness, Centimeters	Coil Power Factor	Per Cent Coil Efficiency	Over-All Efficiency
0.02			
0.04	0.03	44	33
0.08	0.14	89	66

the strip, the function $G(Kt)$ becomes equal to $1/2Kt$, and equation 3 for values of $Kt > 3$ may be written

$$W = \frac{1.26\times10^{-4}}{t} H^2\sqrt{\mu f \rho}$$

watts per cubic centimeter (4)

If it be assumed that the effective or proper value of permeability to substitute in equations 3 and 4 bears a constant ratio to the peak permeability (B/H) at the surface of the strip, it may be written

$$\mu = K_1\left(\frac{B}{H}\right)$$

and substituting in equation 4 gives

$$W = \frac{1.26\times10^{-4}}{t}\sqrt{K_1 B H^3 f \rho}$$

watts per cubic centimeter (5)

The equation was first tested by the writer in this form and was found to agree well with experimental measurements on tin plate 0.010 inch thick induction heated with frequencies of several hundred kilocycles (large Kt values), when the constant K_1 was given the value 1.8. Thus, for this condition it is found that the effective value of permeability to be substituted in the power equation is 1.8 times (B/H), the permeability at the surface of the strip corresponding to the peak magnetizing force, H.

It was only natural to question whether or not this value of μ determined at high Kt values could be used satisfactorily in equation 3 with the curve of Figure 3 to calculate power input at low Kt values. To check this a series of tests was made using magnetic strip (tin-plate stock) ranging in thickness from 0.00115 inch to 0.032 inch and frequencies ranging from 9.6 kilocycles to 490 kilocycles. These tests are described later.

Experimental Check of Equation 3

Although induction heating is often applied to strip 36 inches or more wide, it was decided in view of the large number of measurements necessary to use for the test a section of strip 1.25 centimeters wide by 45 centimeters long, supported in a glass tube (two-centimeters inside diameter) as shown in Figure 4. The coil to carry the high-frequency current and produce the desired heating was five cen-

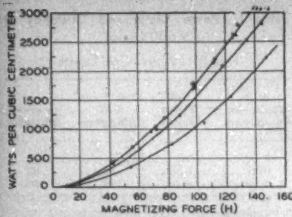

Figure 6. Power generated in 0.0095-inch-thick tin plate with various coil lengths

Frequency—196 kilocycles
Coil lengths:
o—39.3 centimeters
x—29.5 centimeters
Δ—20.8 centimeters
□—12.0 centimeters
▽— 4.8 centimeters

timeters in diameter and 39 centimeters long. It was wound with 61 turns of $^3/_{16}$-inch outside diameter hollow copper tubing and was water-cooled. The power input to the strip was determined from the rate of flow of water through the glass tube and its temperature rise. The temperature of the strip, which in most tests was near or slightly above the boiling point of water, was measured with a thermocouple.

Calculation of Data

In order to correlate the experimental results of many tests it was decided to assume that the form of equation 3 was correct as written with the possible exception that the $G(Kt)$ function of equation 3 might not agree with the theoretical curve of Figure 3 at low values of Kt. Solving equation 3 for this function gives

$$G(Kt) = \frac{2W10^7}{\mu Hf} \qquad (6)$$

By determining W by measurement, calculating H from the current and coil dimensions, evaluating $\mu = 1.8\ (B/H)$, and inserting the value of measured frequency, one can calculate the value of $G(Kt)$ which makes equation 3 agree with the measured power input in any test. In this way an experimental curve for $G(Kt)$ was determined and is shown in Figure 5. It is seen that this curve agrees well with the theoretical curve of Figure 3 except in the region of low Kt values. Thus, it is shown that one may use equation 3 to calculate power input for any value of Kt, but the experimental curve of Figure 5 instead of the theoretical curve of Figure 3 should be used to evaluate $G(Kt)$.

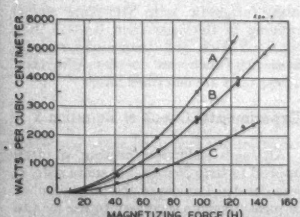

Figure 7. Power generated in 0.007-inch-thick tin plate at various frequencies

A—335 kilocycles
B—193 kilocycles
C— 77 kilocycles

Evaluation of B and H

B is the flux density in gauss corresponding to the peak magnetizing force H and is taken from the magnetization curve of the material to be heated. Usually in induction heating it is necessary to make H greater than 60 to obtain the desired power input so that B may be given a constant (near saturation) value of 18,000.

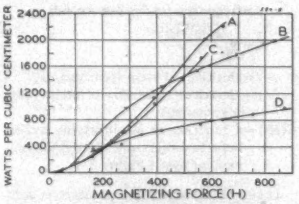

Figure 8. Induction heating of iron strip, 9,600 cycles

A—0.028 inch thick
B—0.014 inch thick
C—0.032 inch thick
D—0.007 inch thick

The magnetizing force was calculated in all cases from the equation,

$$H = 0.4\pi\sqrt{2}nI \text{ oersteds}$$
n = turns per centimeter in coil
I = rms amperes in coil (7)

This equation is accurate only when the coil is long in comparison to its diameter or minimum cross-section dimension.

Experimental Curves of Power Input

The ranges of strip thickness and frequency used in obtaining the composite curve of Figure 5 is illustrated by the curves of Figures 6 to 13 inclusive.

The curves of Figure 6 show the effect of coil length and indicate simply that for short coils, the value of H is not calculated accurately by equation 7. It is seen that the error is negligible for coil lengths greater than 20 centimeters, and all subsequent tests were made with a coil length of 29 centimeters (46 turns).

The curves of Figure 7 show the effect of varying H and frequency. The frequency, strip thickness, and H in these curves correspond to large Kt values, and, as indicated by equation 5, the power input, W, increases with the $^3/_2$ power of H. Recent tests with a single-turn coil heating iron pipe indicate this law to be valid for values of H as great as 1,000.

Figure 8 shows that the shape of the power curves is quite different for thin strip and lower frequencies (low Kt values).

Figures 9 to 13 inclusive show experiment points determined on the $G(Kt)$ curve for various strip thicknesses and frequencies. In each case the theoretical curve is shown dotted for comparison with the experimental points. Most of the points were calculated from measurements for which H was greater than 60. Where points were taken from tests in which H was less than 60, the points are marked with a number corresponding to the H value. In general these points do not correlate as well as points taken at higher values of H.

Limitation of Power Input to Strip

The curves of Figure 14 show the power input to strips of various thicknesses calculated from equation 3, and the experimental curve of Figure 5. These curves are plotted in terms of W', the watts per square centimeter of strip ($W' = tW$). As long as the depth of current penetration ($1/K$) is less than about one third the strip thickness ($Kt > 3$), the current in each face of the strip is equal to the ampere turns of the coil and the power input at constant frequency (9,600 cycles) increases as the $^3/_2$ power of H. This condition is maintained for the 0.16-centimeter-thick strip even up to the highest values of H indicated. When the depth of current penetration becomes greater, due to increasing H, than one third the strip thickness, $Kt < 3$, the currents on the two sides of the strip begin to counteract, and the power input goes up less rapidly than the $^3/_2$ power of H. This is illustrated by the curve for the 0.08-centimeter-thick strip, which begins to drop off at $H = 400$. The curves for the 0.04-centimeter-thick and 0.02-

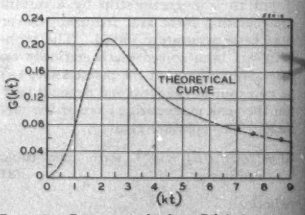

Figure 9. Experimental values G(kt). 0.0095-inch-thick tin plate

Frequency 193 kilocycles

centimeter-thick strips drop off at much lower values of H. In fact the curve for the 0.02-centimeter-thick strip shows very little increase in power input above $H=500$. The copper loss and reactive volt-amperes of the coil increase approximately with the square of H so that, as the power curve begins to flatten, the power factor and efficiency of the induction-heating coil become very low. Thus it is evident that there is a definite practical limit to the power which may be put into a strip of given thickness at any frequency. If the frequency be increased,

Table II. Power Factor and Efficiency at 9,600 Cycles

Ten-Foot Active Coil Length

Strip Thickness, Centimeters	Coil Power Factor	Per Cent Coil Efficiency	Over-All Efficiency
0.02			
0.04	0.08	81	59.5
0.08	0.23	95	71.0

this limiting value of power is, of course, increased. This is described in more detail in the next section.

Power Factor and Efficiency

The power factor of the induction-heating coil is given by the equation

$$\text{Pf}=\frac{W_w+W_c}{VI} \tag{8}$$

where

W_w = total power induced in the strip (watts)
W_c = total copper loss in the coil (watts)
V = coil voltage (rms volts)
I = coil current (rms amperes)

The coil efficiency is given by the equation

$$\text{Coil efficiency}=\frac{W_w\times 100}{W_w+W_c} \tag{9}$$

To determine the value of the factors entering into these equations consider a coil arrangement as shown in Figure 15.

l_c = length of coil (centimeters)
b_c = width of coil (centimeters)
b_s = width of strip (centimeters)
h_c = smaller dimension of coil opening (centimeters)
t = strip thickness (centimeters)

From equation 3 the total power into the strip is

$$W_w=\tfrac{1}{2}\mu H^2 f l_c b_s G(Kt)10^{-7} \text{ watts} \tag{10}$$

Or if H is greater than 60 one may substitute

$$\mu=\frac{1.8\times 18{,}000}{H}$$

in equation 10 to obtain

$$W_w=1.62\times 10^{-3}\sqrt{H}l_c b_s G(Kt) \text{ watts} \tag{11}$$

It is shown in Appendix I that the copper loss in the coil will be approximately

$$W_c=2.31\times 10^{-7} l_c b_c H^2\sqrt{f} \text{ watts} \tag{12}$$

It is also shown that the volt-amperes in the empty coil (no strip) are given by the equation,

$$(\text{VI})_a=2.5K_L f H^2 h_c l_c b_c\times 10^{-8} \text{ volt-amperes} \tag{13}$$

where

K_L = inductance factor of coil

The total volt-amperes of the coil is made up of two components: the volt-amperes $(VI)_a$ due to air flux and $(VI)_t$ due to flux in the iron. This latter is the most difficult and uncertain factor to evaluate, but luckily its value usually will represent a small part of the total volt-amperes of the coil. The writer has chosen to calculate $(VI)_t$ by a method suggested by Rosenberg's work[2] on eddy-current heating. Although the assumptions made by Rosenberg seem very crude, they produce a power equation almost identical with equation 5 of this paper when $K_1=1.8$.

It is assumed that the flux density penetrates from each surface of the strip at the constant value, B, to a depth (δ_f) at which point it suddenly drops to zero.

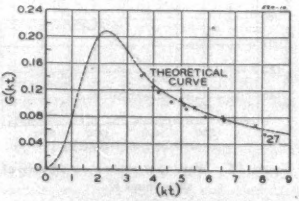

Figure 10. Experimental values G(kt). 0.007-inch-thick tin plate

o—77 kilocycles
x—1.93 kilocycles

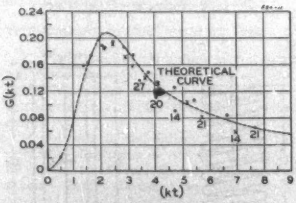

Figure 11. Experimental values G(kt). 0.003-inch-thick tin plate

o— 77 kilocycles
x—168 kilocycles
□—130 kilocycles

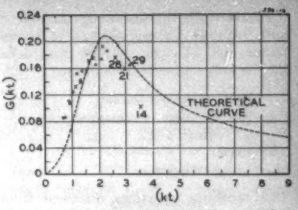

Figure 12. Experimental values G(kt). 0.00115-inch-thick tin plate

o— 88 kilocycles
x—300 kilocycles
Δ—490 kilocycles

This depth of flux penetration is given by the equation,

$$\delta_f=5{,}040\sqrt{\frac{\rho H}{Bf}} \text{ centimeters} \tag{14}$$

It is also assumed that the total flux varies sinusoidally in time and is in phase with the magnetizing force at the surface of the strip.

On these assumptions Appendix II shows that for the condition $\delta_f < t/2$ volt-amperes in the coil due to flux in the iron is given by

$$(VI)_t=5HfB\delta_f b_s l_c\times 10^{-8} \text{ volt-amperes} \tag{15}$$

If δ_f be greater than $t/2$, equation 15 may still be used, but δ_f must be replaced by $t/2$. That is, the flux in the strip cannot increase more after the depth of flux penetration becomes equal to one half the strip thickness. For convenient reference the depth of flux penetration is plotted as a curve in Figure 16.

Because the primary resistance drop in the coil is negligible and because of the way $(VI)_t$ has been obtained, the total volt-amperes in the coil is represented by

$$VI=(VI)_a+(VI)_t \tag{16}$$

and one has all the factors necessary to calculate power factor and efficiency from equations 8 and 9.

Typical Curves of Power Factor and Efficiency at 9,600 Cycles

If it be assumed that the strip and coil are of equal width (a condition which only can be approached in practice) one may calculate W_w, W_c, and VI per square

Table III. Power Factor and Efficiency at 200 Kilocycles

Five-Foot Active Coil Length

Strip Thickness, Centimeters	Coil Power Factor	Per Cent Coil Efficiency	Over-all Efficiency
0.02	0.13	98	59
0.04	0.11	97	58
0.08	0.09	96	57.5

centimeter of strip and using equations 8 and 9 obtain general curves of power factor and efficiency. This was done for the following set of conditions:

$f = 9{,}600$ cycles per second
$\rho = 22 \times 10^{-6}$ ohm centimeters
$K_L = 0.7$ (equation 12)
$B = 18{,}000$
$h_c = 7.5$ centimeters

The resulting equations obtained from equations 11, 12, 13, and 15 and based on one square centimeter of strip are

$$W_c = 0.226 \times 10^{-4} H^2 \quad (17)$$

$$W_w = 15.5 H t G(Kt) \quad (18)$$

$$(VI)_a = 12.6 \times 10^{-4} H^2 \quad (19)$$

$$(VI)_i = 8.62 H \delta_f \quad (20)$$

From these equations and equation 8, values of power factor were calculated and plotted in Figures 17 and 18. Coil efficiency was calculated from these equations and equation 9 and is plotted as curves in Figure 19. These curves indicate in a general way what power density, power factor, and coil efficiency can be obtained at 9,600 cycles when heating strips of various thicknesses.

Consider now the possibility of using 9,600-cycle power to brighten tin plate. This now is being accomplished with 200-kilocycle power under the following conditions:

$N = 1{,}000$ feet per minute
$\rho = 22 \times 10^{-6}$ ohm centimeters
$c = 0.12$
$l_c = 152$ centimeters (five feet)
$t = 0.018$ centimeters to 0.03 centimeters
$\theta = 250$ degrees centigrade

By substitution in equation 2 it is found that the power density necessary is 3,300 watts per cubic centimeter of strip. Values of power factor and efficiency obtainable with this input, taken from the curves of Figures 18 and 19, are listed in Table I. The over-all efficiency is calculated assuming an efficiency of 75 per cent for the motor-generator set. No values are shown for the 0.02-centimeter-thick strip, because it appears impossible to put the necessary power into this strip under any condition. Even for the 0.04-centimeter-thick strip, which is thicker than most tin-plate stock, the efficiency and power factor are still too low to be practical. The 0.08-centimeter-thick strip could, however, be heated quite satisfactorily.

In any case capacitors will be connected in parallel with the coil or in a series–parallel arrangement, as shown in Figure 2, to bring the power factor at the terminals of the generator essentially to 100 per cent.

Conditions could be improved somewhat by making the active length of coil twice as long (ten feet), as shown in Table II. It is still impractical to heat the 0.02-centimeter-thick strip although the 0.04-centimeter-thick strip can be heated with this longer coil at an efficiency comparable to that obtained with the present 200-kilocycle tin-brightening line.

Since most tin-plate production is for a strip thickness of about 0.025 centimeters, it is easy to see why the present installations were set up to use the higher frequency (200 kilocycles). One would not need to jump all the way from 9,600 cycles to 200 kilocycles from the standpoint of the work coil efficiency and power factor, but radio-frequency generators are cheaper and easier to operate at 200 kilocycles than at some lower frequency.

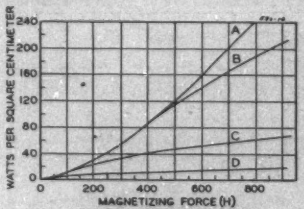

Figure 14. Watts per square centimeter of strip versus H

Frequency—9,600 cycles

Strip thicknesses:

A—0.16 centimeter = 0.063 inch
B—0.08 centimeter = 0.0315 inch
C—0.04 centimeter = 0.0157 inch
D—0.02 centimeter = 0.0078 inch

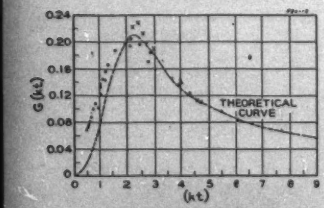

Figure 13. Experimental values of G(kt) for tin plate of various thicknesses

Frequency—9.6 kilocycles

o—0.032 inch thick
x—0.028 inch thick
□—0.014 inch thick
△—0.007 inch thick

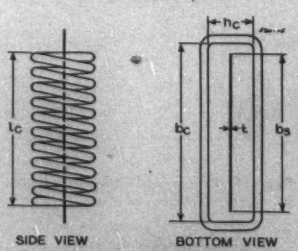

Figure 15. Induction-heating coil

Coil Power Factor and Efficiency at 200 Kilocycles

The same equations used in calculating the curves of Figures 17, 18, and 19 were applied to the problem of heating the same strip thicknesses at 200 kilocycles. The results are shown by the two curves of Figure 20. Since the depth of penetration of flux and current at this higher frequency is less than half the strip thickness, even at the highest power inputs (high values of H), a single curve of power factor and a single curve of efficiency is obtained for all three strip thicknesses when plotting against watts per square centimeter of strip. The crosses on the curves indicate the condition of operation for each strip thickness with a strip speed of 1,000 feet per minute and a temperature rise of 250 degrees centigrade. The values of efficiency and power factor are listed in Table III. The over-all efficiencies are calculated on an assumed efficiency of 60 per cent for the radio-frequency generator (vacuum-tube oscillator). Comparing Tables I and III one sees that, whereas the 0.02-centimeter-thick strip could not be heated at 9,600 cycles, it can be heated more efficiently than thicker strips at 200 kilocycles. The 0.04-centimeter-thick strip can be heated more efficiently at 200 kilocycles than at 9,600 cycles with an active coil length of five feet; however, by going to a coil twice as long this strip can be heated about equally well at both frequencies. The 0.08-centimeter-thick strip can be heated more efficiently at 9,600 cycles than at 200 kilocycles.

Coil Voltage and Current

The equations in the body of this paper have been kept in terms of volt-amperes in the coil rather than considering voltage and current separately. Knowing

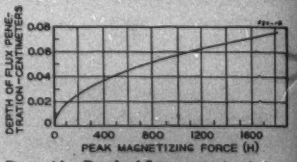

Figure 16. Depth of flux penetration in iron at 9,600 cycles

$\rho = 22 \times 10^{-6}$ ohm-centimeters

$$\delta = 5{,}040 \sqrt{\frac{\rho H}{Bf}}$$

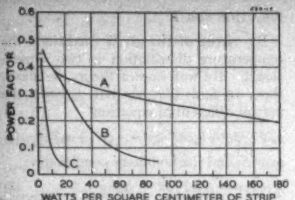

Figure 17. Coil power factor versus watts per square centimeter of strip, 9,600 cycles

Strip thicknesses:

A—0.08 centimeter = 0.0315 inch
B—0.04 centimeter = 0.0157 inch
C—0.02 centimeter = 0.0079 inch

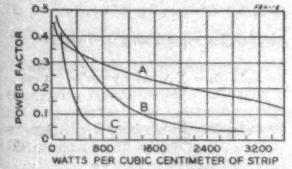

Figure 18. Coil power factor versus watts per cubic centimeter of strip, 9,600 cycles

Strip thicknesses:

A—0.08 centimeter = 0.0315 inch
B—0.04 centimeter = 0.0157 inch
C—0.02 centimeter = 0.0079 inch

the total volt-amperes of the coil, one may, after fixing on the number of turns per centimeter, determine the coil current from the value of H necessary to obtain the desired power density in the strip. The volt-amperes of the coil divided by this current will give the voltage across the coil with this current flowing.

Conclusions

Some heat can be generated in magnetic strip at even low frequencies, but there is for every strip thickness and frequency a definite practical limit to the density of heating possible. For any strip thickness and frequency the power factor and coil efficiency drop off with increasing power density as shown by the curves of Figures 17 to 20 inclusive. At strip speeds of 1,000 feet per minute and a temperature rise of 250 degrees centigrade, strips thicker than 0.04 centimeters (0.0157 inch) can be heated satisfactorily at 9,600 cycles. For thinner strips vacuum-tube or other type of generator must be used to supply a higher frequency. If the temperature rise be increased, the strip speed must be reduced proportionately to keep the power density constant.

Iron or steel strip cannot be heated

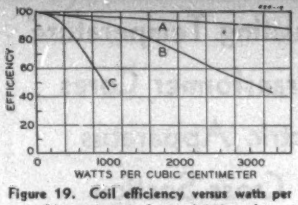

Figure 19. Coil efficiency versus watts per cubic centimeter of strip, 9,600 cycles

Strip thickness:

A—0.08 centimeter = 0.0315 inch
B—0.04 centimeter = 0.0157 inch
C—0.02 centimeter = 0.0079 inch

economically above the Curie point (700 to 800 degrees centigrade) by induction heating as described in this paper.

Appendix I

Coil Copper Loss

Consider a coil consisting of a single wide sheet of copper forming a turn around the strip to be heated. Current supplied to this turn will concentrate almost entirely on the inside surface, and, if the current be adjusted to give a magnetizing force, H, in the space between the coil and the strip, the copper loss in watts per square centimeter of inside surface will be just that which would be produced by induction heating a sheet of copper in a magnetic field of strength, H. This can be shown to be[3]

$$W = 0.63\times10^{-4}H^2\sqrt{\rho f} \text{ watts per square centimeter} \quad (21)$$

Substituting the value $\rho = 2\times10^{-6}$ ohm centimeters for copper and multiplying by the total inner surface area of the coil, $2b_cl_c$, gives for the total power

$$W_c' = 1.78\times10^{-5}b_cl_cH^2\sqrt{f} \text{ watts} \quad (22)$$

Experience indicates that with a turn spacing of from one fourth to one conductor diameter, the actual loss is approximately 1.3 times that indicated by equation 22 or the total copper loss is

$$W_c = 2.31\times10^{-5}\eta_cb_cH^2\sqrt{f} \text{ watts} \quad (23)$$

The number of turns obviously does not enter into the calculation of total loss.

Volt-Amperes in Coil Due to Air Flux

The strip usually will occupy such a small fraction of the total volume of the coil that the volt-amperes due to air flux may be considered equal to the volt-amperes of the empty coil.

If the ratio of coil section length to the minimum dimension of coil opening (l_c/h_c) be greater than four, the heating observed seems to justify the use of the equation,

$$H = 0.4\pi\sqrt{2nI} \text{ oersteds} \quad (24)$$

to calculate the peak value of magnetizing force in the coil. However only part of the

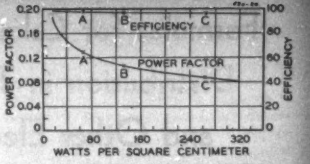

Figure 20. Coil power factor and efficiency versus watts per square centimeter of strip, 200 kilocycles

A—t = 0.02 centimeter (1,000 feet per minute)
B—t = 0.04 centimeter (1,000 feet per minute)
C—t = 0.08 centimeter (1,000 feet per minute)

total flux b_ch_cH cuts all the turns of the coil. The voltage induced in the coil is

$$V_a = \sqrt{2}\pi fnl_cK_Lb_ch_cH\,10^{-8} \text{ volts (rms)} \quad (25)$$

where K_L = voltage factor of coil and has a value of about 0.7 when the ratio l_c/h_c is between four and six. K_L will approach unity for a long coil.

The current in the coil from equation 24 is

$$I = \frac{H}{0.4\pi\sqrt{2n}} \text{ amperes (rms)} \quad (26)$$

Multiplying equations 25 and 26 the volt-amperes of the coil due to air flux is found to be

$$(VI)_a = 2.5K_LfH^2h_cl_cb_c\times10^{-8} \text{ volt-amperes} \quad (27)$$

Appendix II. Volt-Amperes in Coil Due to Flux in the Iron

If flux penetrates at density B to a depth δ_f from each surface of the strip, the total flux in the iron is $2b_c\delta_fB$. The voltage induced in the coil by this flux is

$$V_i = \sqrt{2}\pi fnl_c2b_c\delta_fB\times10^{-8} \quad (28)$$

Multiplying this by the coil current from equation 26 gives for the coil volt-amperes due to flux in the iron,

$$(VI)_i = 5Hfl_cB\delta_fb_c\times10^{-8} \text{ volt-amperes} \quad (29)$$

It is obvious, as indicated in the body of the paper, that, if δ_f becomes greater than one half the strip thickness it must be replaced by $t/2$.

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Formulas for Calculating Temperature Distribution in Transformer Cores and Other Electric Apparatus of Rectangular Cross Section

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THIS paper comprises solution of a very general problem in the mathematical theory of heat; application of it to effect formulas for the temperature distribution T, the maximum temperature T_m, and the average temperature T_a in transformer cores; and indication of its use with reference to other electric apparatus of rectangular cross section and of such general shape that the temperature distribution is essentially two dimensional. As theory indicates and experiment confirms that this condition is often fulfilled in practice, these formulas ought to be of considerable interest to designers of such equipment. For, commonly, the maximum electric loading of an electric device is determined by the permissible maximum or hot-spot temperature in it. Hence knowledge of this maximum temperature and of the temperature distribution in general is desired by the designer faced with making up new designs, improving operating performance of existing designs, or deciding upon maximum, yet safe, overload limits for apparatus already in service.

This work falls naturally into two parts. The first encompasses statement of the problem in the theory of heat; mathematical formulation of this problem, solution for the general temperature distribution, T, by the well-known method of expansions in infinite series, and derivation therefrom of formulas for the maximum and average temperatures, T_m and T_a and expression of special forms for T, T_m, and T_a. The second part embraces interpretation of the formulas derived in the first in reference to application to transformer cores; illustration of use thereto through calculation of the maximum temperature in a specified core and comparison with the corresponding experimental value; discussion of application to calculating temperatures in toroidal electric coils of rectangular cross section; and mention of other uses.

Derivation of Formulas

Statement of Problem

The axis of a homogeneous infinite rectangular cylinder coincides with the z axis of a system of rectangular coordinates; the sides of the rectangular cross section, S, of width $2a$ and height $2b$ are directed parallel to the x and y axes (Figure 1). The thermal conductivities in the x and y direction are k_x and k_y. The rate of internally generated heat density is $q_0(1+\alpha_0 T)$, where of q_0 and α_0 are arbitrary constants. From the face of the cylinder f_i ($i=1, 2, 3, 4$) heat is transferred to the adjacent medium according to the relationship, $T-T_i=-K_i\partial T/\partial n$; where of n denotes the outward drawn normal to f_i; $K_i=R_i k_n$,

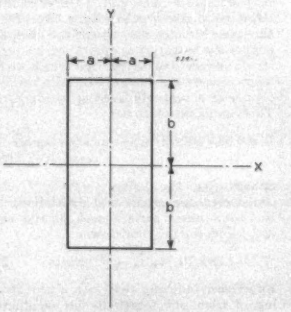

Figure 1

wherein R_i designates the surface thermal resistivity of f_i and k_n the thermal conductivity in the direction of n; and regarding a point in f_i, T and T_i are respectively the corresponding temperatures in the cylinder and in the immediately adjacent ambient medium. No restriction is made as to the distribution of T_i over f_i except that it be expressible in a generalized Fourier series. What is required is the temperature distribution $T(x, y)$, the maximum temperature T_m, and the average temperature T_a of the cylinder.

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Solution for T

By virtue of the given conditions the temperature distribution is two dimensional. By well-known theory we have, then, to find $T(x, y)$ that satisfies the partial differential equation

$$k_x\partial^2 T/\partial x^2+k_y\partial^2 T/\partial y^2=-q_0(1+\alpha_0 T) \quad (1)$$

over S, and the boundary conditions

$$T-T_1=-K_1\partial T/\partial x \qquad x=a \quad (2)$$

$$T-T_2=K_2\partial T/\partial x \qquad x=-a \quad (3)$$

$$T-T_3=-K_3\partial T/\partial y \qquad y=b \quad (4)$$

$$T-T_4=K_4\partial T/\partial y \qquad y=-b \quad (5)$$

Rearranging equation 1 yields

$$\partial^2 T/\partial x^2+k\partial^2 T/\partial y^2+C^2 T=-C' \quad (6)$$

wherein

$$k=k_y/k_x;\ C^2=q_0\alpha_0/k_x;\ C'=q_0/k_x \quad (7)$$

Rearranging equations 2 to 5 yields

$$T+K_1\partial T/\partial x=\sum_{i=1}^{\infty} S_i\cos(s_i y+s_i') \qquad x=a \quad (8)$$

$$T-K_2\partial T/\partial x=\sum_{i=1}^{\infty} S_i'\cos(s_i y+s_i') \qquad x=-a \quad (9)$$

$$T+K_3\partial T/\partial y=\sum_{i=1}^{\infty} P_i\cos(p_i x+p_i') \qquad y=b \quad (10)$$

$$T-K_4\partial T/\partial y=\sum_{i=1}^{\infty} P_i'\cos(p_i x+p_i') \qquad y=-b \quad (11)$$

wherein the right-hand members are respectively the generalized Fourier expansions of T_1 and T_3 over $-b\leq y\leq b$ and of T_2 and T_4 over $-a\leq x\leq a$.

The procedure for solving equation 6 pursuant to equations 8 to 11 is: Symbolize the left-hand member of equation 6 as an operator $\nabla=(\partial^2/\partial x^2+k\partial^2/\partial y^2+C^2)$ operating on T, and find a particular solution of equation 6. Add to this functions F involving arbitrary constants so related that $\nabla F=0$, whence the resulting sum is also a solution of equation 6. Substitute this resulting expression in equations 8 to 11. Solve the resulting set of equations for values of the constants, whence T is now determined.

Thus, we assume T to be of the form

$$T=\sum_{i=1}^{\infty} A_i\cos(m_i x+m_i')\cosh(n_i y+n_i')+\sum_{i=1}^{\infty} B_i\cos(p_i x+p_i')\cosh(q_i y+q_i')+\sum_{i=1}^{\infty} C_i\cosh(r_i x+r_i')\cos(s_i y+s_i')+\sum_{i=1}^{\infty} D_i\cos(m_i x+m_i') \quad (12)$$

Substituting equation 12 in equation 6 yields

$$\sum_{i=1}^{\infty} A_i(-m_i^2+kn_i^2+C^2)\cos(m_i x+m_i')\times\cosh(n_i y+n_i')+\sum_{i=1}^{\infty} B_i(-p_i^2+kq_i^2+C^2)\times\cos(p_i x+p_i')\cosh(q_i y+q_i')+$$

$$\sum_{i=1}^{\infty} C_i(r_i^3 - ks_i^3 + C^3)\cosh(r_i x + r_i')\times \cos(s_i y + s_i') +$$

$$\sum_{i=1}^{\infty} D_i(-m_i^3 + C^3)\cos(m_i x + m_i') = -C' \quad (13)$$

Assuming

$$n_i = [(m_i^3 - C^3)/k]^{1/3} \quad (14)$$

$$q_i = [(p_i^3 - C^3)/k]^{1/3} \quad (15)$$

$$r_i = (ks_i^3 - C^3)^{1/3} \quad (16)$$

we have from equation 13

$$\sum_{i=1}^{\infty} D_i(-m_i^3 + C^3)\cos(m_i x + m_i') = -C' \quad (17)$$

Now as derived in the appendix, the generalized Fourier expansion of $-C'$ is

$$-C' = -\sum_{i=1}^{\infty}(4C'\sin m_i a\cos m_i')(2m_i a + \sin 2m_i a\cos 2m_i')^{-1}\cos(m_i x + m_i') \quad (18)$$

Comparing corresponding coefficients of the cosine terms in the left-hand member of equation 17 and the right-hand member of equation 18 we find for D_i

$$D_i = (4C'\sin m_i a\cos m_i')(m_i^3 - C^3)^{-1}\times (2m_i a + \sin 2m_i a\cos 2m_i')^{-1} \quad (19)$$

Accordingly, equation 12 satisfies equation 6 pursuant to equations 14, 15, 16, and 19. We proceed to determine values of the remaining constants such that equation 12 will satisfy the boundary conditions.

Substituting equation 12 in equations 8 to 11 yields

$$\sum_{i=1}^{\infty} A_i[\cos(m_i a + m_i') - K_1 m_i\times \sin(m_i a + m_i')]\cosh(n_i y + n_i') +$$

$$\sum_{i=1}^{\infty} B_i[\cos(p_i a + p_i') - K_1 p_i\times \sin(p_i a + p_i')]\cosh(q_i y + q_i') +$$

$$\sum_{i=1}^{\infty} C_i[\cosh(r_i a + r_i') + K_1 r_i\times \sinh(r_i a + r_i')]\cos(s_i y + s_i') +$$

$$\sum_{i=1}^{\infty} D_i[\cos(m_i a + m_i') - K_1 m_i\times \sin(m_i a + m_i')] = \sum_{i=1}^{\infty} S_i\cos(s_i y + s_i') \quad (20)$$

$$\sum_{i=1}^{\infty} A_i[\cos(m_i a - m_i') - K_2 m_i\times \sin(m_i a - m_i')]\cosh(n_i y + n_i') +$$

$$\sum_{i=1}^{\infty} B_i[\cos(p_i a - p_i') - K_2 p_i\times \sin(p_i a - p_i')]\cosh(q_i y + q_i') +$$

$$\sum_{i=1}^{\infty} C_i[\cosh(r_i a - r_i') + K_2 r_i\times \sinh(r_i a - r_i')]\cos(s_i y + s_i') +$$

$$\sum_{i=1}^{\infty} D_i[\cos(m_i a - m_i') - K_2 m_i\times \sin(m_i a - m_i')] = \sum_{i=1}^{\infty} S_i'\cos(s_i y + s_i') \quad (21)$$

$$\sum_{i=1}^{\infty} A_i[\cosh(n_i b + n_i') + K_3 n_i\times \sinh(n_i b + n_i')]\cos(m_i x + m_i') +$$

$$\sum_{i=1}^{\infty} B_i[\cosh(q_i b + q_i') + K_3 q_i\times \sinh(q_i b + q_i')]\cos(p_i x + p_i') +$$

$$\sum_{i=1}^{\infty} C_i[\cos(s_i b + s_i') - K_3 s_i\times \sin(s_i b + s_i')]\cosh(r_i x + r_i') +$$

$$\sum_{i=1}^{\infty} D_i\cos(m_i b + m_i') = \sum_{i=1}^{\infty} P_i\cos(p_i x + p_i') \quad (22)$$

$$\sum_{i=1}^{\infty} A_i[\cosh(n_i b - n_i') + K_4 n_i\times \sinh(n_i b - n_i')]\cos(m_i x + m_i') +$$

$$\sum_{i=1}^{\infty} B_i[\cosh(q_i b - q_i') + K_4 q_i\times \sinh(q_i b - q_i')]\cos(p_i x + p_i') +$$

$$\sum_{i=1}^{\infty} C_i[\cos(s_i b - s_i') - K_4 s_i\times \sin(s_i b - s_i')]\cosh(r_i x + r_i') +$$

$$\sum_{i=1}^{\infty} D_i\cos(m_i x + m_i') = \sum_{i=1}^{\infty} P_i'\cos(p_i x + p_i') \quad (23)$$

When we take in equation 20

$$\tan(m_i a + m_i') = 1/K_1 m_i \quad (24)$$

$$\tan(p_i a + p_i') = 1/K_1 p_i \quad (25)$$

the first, second, and fourth terms of the left-hand member disappear and we have, on equating coefficients of corresponding cosine terms,

$$C_i[\cosh(r_i a + r_i') + K_1 r_i\sinh(r_i a + r_i')] = S_i' \quad (26)$$

Similarly, if in equation 21 we take

$$\tan(m_i a - m_i') = 1/K_2 m_i \quad (27)$$

$$\tan(p_i a - p_i') = 1/K_2 p_i \quad (28)$$

we obtain

$$C_i[\cosh(r_i a - r_i') + K_2 r_i\sinh(r_i a - r_i')] = S_i' \quad (29)$$

From equation 22, providing

$$\tan(s_i b + s_i') = 1/K_3 s_i \quad (30)$$

$$A_i[\cosh(n_i b + n_i') + K_3 n_i\sinh(n_i b + n_i')] + D_i = 0 \quad (31)$$

we obtain

$$B_i[\cosh(q_i b + q_i') + K_3 q_i\sinh(q_i b + q_i')] = P_i \quad (32)$$

Finally, from equation 23, providing

$$\tan(s_i b - s_i') = 1/K_4 s_i \quad (33)$$

$$A_i[\cosh(n_i b - n_i') + K_4 n_i\sinh(n_i b - n_i')] + D_i = 0 \quad (34)$$

we obtain

$$B_i[\cosh(q_i b - q_i') + K_4 q_i\sinh(q_i b - q_i')] = P_i' \quad (35)$$

Solving equations 24 and 27 simultaneously yields the values of m_i and m_i'; similarly the values of p_i and p_i' and of s_i and s_i' are furnished by simultaneous solution of equations 25 and 28 and of equations 30 and 33. Nomograms affording graphical solution of these pairs of equations are to be found in reference 2. Inasmuch as m_i, p_i, and s_i are determined, equations 14, 15, and 16 respectively yield n_i, q_i, and r_i. But n_i now being known, n_i' and A_i are the only unknowns in equations 31 and 34. Accordingly, equating the right-hand members, canceling D_i and then A_i, expanding the hyperbolic terms, and solving for $\tanh n_i'$ and thence n_i', we have

$$n_i' = \tanh^{-1}(K_4 - K_3)[(2/n_i) + (K_3 + K_4)\coth n_i b]^{-1} \quad (36)$$

In equations 31 and 34 A_i is now the only unknown. Thus, from equation 31

$$A_i = -D_i[\cosh(n_i b + n_i') + K_3 n_i\sinh(n_i b + n_i')]^{-1} \quad (37)$$

Again, r_i being known in equations 26 and 29, r_i' and C_i are the only unknowns. Thus, dividing left and right-hand members of equations 26 and 29 to eliminate C_i, expanding the hyperbolic terms, solving for $\tanh r_i'$ and thence r_i', we have

$$r_i' = \tanh^{-1}\frac{[(\cosh r_i a + K_1 r_i\sinh r_i a)S_i' - (\cosh r_i a + K_3 r_i\sinh r_i a)S_i]}{[(\sinh r_i a + K_1 r_i\cosh r_i a)S_i' - (\sinh r_i a + K_3 r_i\cosh r_i a)S_i]} \quad (38)$$

In equations 26 and 29 C_i is now the only unknown. Thus from equation 26

$$C_i = S_i[\cosh(r_i a + r_i') + K_1 r_i\sinh(r_i a + r_i')]^{-1} \quad (39)$$

In analogous fashion we obtain from equations 32 and 35

$$q_i' = \tanh^{-1}\frac{[(\cosh q_i b + K_3 q_i\sinh q_i b)P_i' - (\cosh q_i b + K_4 q_i\sinh q_i b)P_i]}{[(\sinh q_i b + K_3 q_i\cosh q_i b)P_i' - (\sinh q_i b + K_4 q_i\cosh q_i b)P_i]} \quad (40)$$

and

$$B_i = P_i[\cosh(q_i b + q_i') + K_3 q_i\sinh(q_i b + q_i')]^{-1} \quad (41)$$

Accordingly, all constants in equation 12 being determined, we have the complete solution for T.

Solution for T_m

T is a function of two variables. The form of T—the sum of four infinite series—renders unfeasible determination of the maximum temperature by application of the rules of the calculus for determining maxima and minima of functions of two variables. In general, the maximum temperature is to be ascertained by plotting the temperature distribution over that region of the cross section which a preliminary calculation, or consideration of given physical conditions, indicates as encompassing T_m. If, however, the temperature distribution be symmetrical about each of the co-ordinate axes (that

is, $K_1=K_3$, $K_2=K_4$, $S_i=S_i'$, $P_i=P_i'$), T_m occurs at $x=0$, $y=0$. Hence, for this case, which, in fact, is that usually encountered in practice

$$T_m=\sum_{i=1}^{\infty} A_i \cos m_i' \cosh n_i' + \sum_{i=1}^{\infty} B_i \cos p_i' \times \cosh q_i' + \sum_{i=1}^{\infty} C_i \cosh r_i' \cos s_i' + \sum_{i=1}^{\infty} D_i \cos m_i' \quad (42)$$

Solution for T_a

The average temperature T_a over the cross section is given by

$$T_a=(1/ab)\int_{-a}^{a}\int_{-} T\,dx\,dy \quad (43)$$

Substituting equation 12 in equation 43 and integrating yields

$$T_a=(1/ab)[\sum_{i=1}^{\infty} A_i \sin m_i a \cos m_i' \sinh \times n_i b \cosh n_i'/m_i n_i + \sum_{i=1}^{\infty} B_i \sin p_i a \cos p_i' \sinh \times q_i b \cosh q_i'/p_i q_i + \sum_{i=1}^{\infty} C_i \sin s_i b \sin s_i' \sinh \times r_i a \cosh r_i'/r_i s_i + \sum_{i=1}^{\infty} D_i b \sin m_i a \cos m_i'/n_i] \quad (44)$$

Special Forms

For reasons which will follow it is convenient to have the equations that stem from expressing the temperature in the form

$$T=T'+T_a;\quad T_i=T_i'+T_a \quad (45)$$

wherein T_a is an arbitrary constant.

Substituting equation 45 in equation 1 yields

$$\partial^2 T'/\partial x^2+k\partial^2 T'/\partial y^2+C^2T'=-C'' \quad (46)$$

wherein

$$C''=q_0(1+\alpha_0 T_a)/k_x \quad (47)$$

Substituting equation 45 in equations 2 to 5 yields

$$T'-T_1'=-K_1\partial T'/\partial x \qquad x=a \quad (48)$$

$$T'-T_2'=K_2\partial T'/\partial y \qquad y=-a \quad (49)$$

$$T'-T_3'=-K_3\partial T'/\partial y \qquad y=b \quad (50)$$

$$T'-T_4'=K_4\partial T'/\partial y \qquad y=-b \quad (51)$$

wherein

$$T_i'=T_i-T_a \quad (i=1, 2, 3, 4) \quad (52)$$

By virtue of the formal identity of equation 46 with equation 6 and of equations 48 to 51 with equations 2 to 5 we have at once that the solution for T' is afforded by that for T, if therein we replace C' by C'' and interpret S_i, S_i', P_i, and P_i' as the coefficients of the generalized Fourier expansions of, respectively, T_1', T_2', T_3', and T_4'. A similar conclusion holds for T_m' and T_m and for T_a' and T_a, whence

$$T_m=T_m'+T_a;\quad T_a=T_a'+T_a \quad (53)$$

The transformations indicated by equations 45 and 53 are of particular interest because they afford very rapid solution of T for the practically important case of $T_1=T_2=T_3=T_4=T_r$. For then, interpreted as the Fourier coefficients of $T_1'=T_2'=T_3'=T_4'=0$, $S_i=S_i'=P_i=P_i'=0$; and the boundary equations for T' are much simpler than the corresponding equations for T. Whence T', and thus $T=T'+T_r$, can be found more quickly than could T, if this latter were to be evaluated directly from the equations given in stating the problem.

Application of Formulas

Transformer Cores

Formulas for calculating temperature distribution in transformer cores of rectangular cross section have been derived by Cockroft,[1] Roth,[2] and Buchholz.[3] Their procedures are alike: determination of the desired formulas is posed as a boundary-value problem in the mathematical theory of heat (in fact, as a special case of that treated in stating the problem). Solution of this problem is effected in some well-known fashion. That the assumptions enabling pose of temperature determination as a boundary-value problem in heat theory are valid under appropriate geometrical conditions[3] is confirmed by the excellent agreement obtained by Roth between corresponding experimentally and analytically (from his formula) determined values of the temperature at points in the cross section of a small single-phase transformer. That the boundary conditions of practice are as indicated by equations 2 to 5 is substantiated by Cockroft's plots of data obtained from transformer-core temperature investigations sponsored by the Metropolitan-Vickers Company.

Cockroft considers the case of uniform generated heat density with thermal resistivity different on adjacent sides but identical over opposite sides in the adjacent ambient medium. Roth extends Cockroft's solution to encompass thermal resistivity different on each side; additionally, he advances the solution for nonuniform generated heat density with thermal resistivity different on each side. This latter work encompasses Buchholz's consideration of nonuniform generated heat density and boundary conditions of thermal resistivity identical over all sides and uniform temperature of adjacent ambient medium. Yet Roth's solutions, the most general available, do not encompass such practically important cases as that of a core with oil duct through the cross section (hence a nonconstant temperature distribution in the ambient medium along the lower edge of the upper half of the cross section) and of such area of cross section that the influence of the nonuniform generated heat density due to change of electric resistivity of the iron with temperature cannot be neglected.

The solution of this case—and of yet more general problems—is, however, afforded by the formulas derived in the first part of this paper. We need only interpret k_x and k_y as the thermal conductivities in the core, α_0 as the temperature coefficient of resistance at zero degrees centigrade of the core iron, q_0 as the generated heat density due to core losses in the iron at zero degrees centigrade, and R_i ($i=1, 2, 3, 4$) as the surface thermal resistivities of the core faces; express the temperature distribution in the ambient medium as a generalized Fourier series; and through appropriate substitution of these data obtain T, T_m, and T_a.

Values of the just mentioned physical constants for typical materials are to be found in the papers of Cockroft, Roth (exhaustive treatment), and Buchholz. The value of q_0, the rate of generated heat density due to eddy currents and hysteresis losses, can be calculated from well-known formulas.

A Numerical Example

To illustrate application of the formulas derived in the first part of this paper to calculation of transformer temperatures we consider the following problem: to calculate the maximum temperature rise in the single-phase transformer tested by Roth.

Given Data. Single-phase transformer with rectangular cross section, $a=4$ cm, $b=6.75$ cm, laminations parallel to edges $2a$; measured maximum temperature rise equals 85 degrees centigrade above temperature of ambient medium; transformer gives up heat to ambient medium, which is air at temperature T_a; core loss = 0.0678 watt per cubic centimeter.

Derived Data. We have $k_x=0.32$ watt per centimeter per degree centigrade; $k_y=0.005$ watt per centimeter per degree centigrade; $k={}^1/_{64}$; $R_1=R_3=1{,}000/3$ square centimeter per watt per degree centigrade; $R_2=R_4=1{,}000/1.92$ square centimeter per watt per degree centigrade—values given by Roth as typical for the transformer tested. Hence, $K_1=K_3=R_1k_x=106.6$ centimeters; $K_2=K_4=R_2k_y=2.6$ centimeters. Inasmuch as no specific statement is made, we assume that the given core loss is the steady-state or hot core loss per unit volume of core. Necessarily, therefore, we consider it the average operating core loss and neglect nonuniformity due to temperature distribution. This assumption implies, as reference to equations 1 and 7 substantiates, that $q=q_0(1+\alpha_0 T)\approx 0.0678$ watt per cubic centimeter; whence $C'=0$ and $C''=q/k=0.212$. It is to be expected that in this instance no appreciable error is introduced by the neglect of nonuni-

formity of core loss due to temperature distribution: for the cross section is small; only the eddy-current losses are affected by variation in the temperature coefficient of resistance; the slight error introduced may be compensated by other small errors, for example, the effect of the not exactly uniform magnetic field on the distribution of hysteresis losses and so forth.

Formula for T_m'. Making use of the special forms already given, we have $P_4=P_4'=S_4=S_4'=0$; from given data, $K_1=K_3$, $K_2=K_4$, $C^2=0$. When these values are used equations 36, 39, and 41 yield $n_4'=C_4=B_4=0$. Accordingly, by equation 12 we need determine further only m_4, m_4', n_4, A_4 and B_4. Equations 24 and 27 yield $m'=0$ and tan $m_4a=(K_3m_4)^{-1}$, and from equation 14 we obtain $n_4=m_4/k^{1/2}$. With these values we obtain from equations 19 and 37

$$D_4=4C^2 \sin m_4a/m_4^3(2m_4a+\sin 2m_4a)$$
$$A_4=-4C^2 \sin m_4a/m_4^3(2m_4a+\sin 2m_4a)\times(\cosh n_4b+K_3n_4 \sinh n_4b)$$

Finally, substituting appropriately in equation 12 and taking $x=y=0$, we have for T_m'

$$T_m'=4C^2\sum_{4=1}^{\infty}[\sin m_4a/m_4^3(2m_4a+\sin 2m_4a)][1-(\cosh n_4b+K_3n_4\times\sinh n_4b)^{-1}] \quad (54)$$

Numerical Values of T_m and T_a. Using the above derived values of q, k_x, k_y, K_1, and K_3, we find by direct calculation

$m_1a=0.1925$; $m_2=0.0481$; $n_1=0.3848$; $n_1b=2.605$
$m_2a=3.1535$; $m_2=0.7884$; $n_2=6.3072$; $n_2b=42.57$
$\sin m_1a=0.1913$; $\sin 2m_1a=0.3756$; $\cosh n_1b=6.802$; $\sinh n_1b=6.728$
$\sin m_2a=-0.0124$; $\sin 2m_2a=0.0248$; $\cosh n_2b=\sinh n_2b>10^{18}$

Substituting appropriately in equation 54, we obtain

$$T_m'=85.3°-0.00216°+\ldots=85.3°$$

This value is but 0.3 degrees centigrade greater than the measured value.

Note that the infinite series of equation 54 converges so rapidly that it is necessary to use only the first term! All computations were performed on a 20-inch slide rule; values of trigonometric and hyperbolic functions are taken from standard tables having arguments in radian measure.

Electric Coils

A current-carrying toroidal coil of rectangular cross section, comprised of many turns of insulated wire of circular or of rectangular cross section, is an important component of many electric devices. Commonly, the coil is either exposed to the atmosphere—as, for example, are the field coils of a dynamo—or is submerged in a liquid—as, for example, are the coils of a transformer. Usually, conditions are such that the temperature distribution in the coil is substantially independent of the angular co-ordinate of a system of cylindrical co-ordinates, the longitudinal axis of which is the axis of the coil. If so, the temperature distribution is two-dimensional, that is, it is the same over any cross section of the coil.

In use the heat generated in the coil results in a general temperature rise throughout the coil. In consequence, a point of maximum temperature is to be found in the cross section. By virtue of the assumed angular symmetry this maximum temperature is the maximum temperature in the coil. Now, in that the permissible maximum coil current is that which produces a specified maximum temperature in the coil, and in that the hot or operating resistance of the coil depends on (and can be calculated from) the average temperature of the coil, formulas for predetermining the temperature distribution, maximum temperature, and average temperature are of considerable interest to the designer of toroidal coils.

A comprehensive discussion of the physical bases underlying derivation of such formulas comprises a recent lengthy paper by the writer.[4] For explicit details the reader is referred to this paper. For present purposes it suffices to remark that following epitomization of the work of Binder,[5] Humburg,[6] Jakob,[7,8] Ott,[9] Punga,[10] Rogowski,[11,12] and Vidmar,[13] a careful consideration of the individual and collective effects of the various physical and geometric factors involved leads to the conclusion that, if a toroidal coil, *i*, is comprised of many turns of thinly insulated wire of comparatively small cross section, *ii* is of rectangular cross section, and *iii* is of a ratio of outer to inner radius greater than (roughly) two, determination of T, T_a, and T_m for the coil—internally generated heat and change of wire resistance with temperature being taken into account—can be posed as a more or less complex two-dimensional boundary-value problem in the mathematical theory of heat, capable of solution by known methods. Illustratively, the solution for the boundary-value condition of constant surface temperature is obtained and it is shown that this solution encompasses, as special cases, the earlier analytic solutions of Humburg,[6] Jakob,[7,8] and Rogowski.[11,12]

The more important problems that arise in practice are, however, not encompassed in the comparatively simple boundary condition of constant temperature. Experiment shows that the boundary condition is commonly that of equations 2 to 5. Solutions for such a boundary condition have been advanced by Roth[2] and Buchholz.[14] The latter takes into account variation of wire resistance with temperature but considers only the case of constant temperature in the adjacent ambient medium with the same thermal resistivity on opposite sides of the rectangular cross section. On the other hand, though Roth encompasses a thermal resistivity and a (constant) temperature of adjacent medium different for each of the four sides of the rectangular cross section, he has not—because (as he states) of the analytic difficulties involved—taken into account the change in resistance of the wire with temperature. Thus, though the formulas of Buchholz and Roth cover a number of problems actually encountered in practice, they do not cover problems of such practical importance as that of calculating the temperature in a rectangular toroidal coil wound in the slot of a spool, wound around a heat-conducting core, or otherwise so disposed that the thermal resistances on the sides are such that they are not encompassed in Buchholz's solution and whereof the electric loading is such that change of wire resistivity with temperature has a marked effect on the temperature distribution over the cross section (the considerable influence of even small variations over the cross section in wire resistivity is strikingly illustrated by the curves contained in Jakob's paper).

The solutions of such cases and of many others are, however, afforded by the formulas derived in the first part of the paper. Thus, we need only interpret k_x and k_y as the equivalent thermal conductivities of the coil (analytic methods of calculating these and physical data essential thereto are to be found in References 2 and 8); α_0 as the temperature coefficient of resistance at zero degrees centigrade of the coil wire; $q_0=I^2R_0/V$ whereof I is the coil current, V the coil volume, R_0 the resistance of the coil at zero degrees centigrade; and R_i the appropriate surface thermal resistance of the coil (numerical values for various materials are to be found in Reference 2). Then we express the temperature distribution in the ambient medium adjacent to each of the four edges in terms of its equivalent generalized Fourier series and through appropriate substitution of these data obtain T, T_m, and T_a from equations 12, 42 (if applicable), and 44 or from the equivalent equations 45 and 53.

In that calculation of the temperature distribution in electric coils by the formulas mentioned involves nothing not already demonstrated by the numerical example given, it does not seem desirable to take space for additional calculations on electric coils. The interested reader is referred to the numerical examples to be found in the writer's[4] first paper on temperature distribution in electric coils and in an unpublished paper wherein formulas, expressed in Fourier–Bessel series, are derived for coils of such radii that the toroidal geometry must be taken into account. In each example calculated values are found to be in close agreement with corresponding values determined by experiment.

Other Applications

The formulas derived in the first part of the paper are applicable to the determination of temperature distribution in bus bars of rectangular cross section, in conductors of rectangular cross section lying in the armature slots of large rotating machines, and to problems in other physical domains that are defined by equations 1 to 5 and proper interpretation of the symbols therein.

Appendix

Over the range $-a \leq x \leq a$ a function $f(x)$ that satisfies certain necessary conditions (usually fulfilled by functions encountered in actual practice) can be expanded in a generalized Fourier series

$$f(x) = \sum_{i=1}^{\infty} M_i \cos(m_i x + M_i')$$

whereof

$$\tan(m_i a + m_i') = C_1/m_i$$

$$\tan(m_i a - m_i') = C_2/m_i$$

C_1 and C_2 are arbitrary constants, and M is given by

$$M_i = 2m_i(2m_i a + \sin 2m_i a \cos 2m_i')^{-1} \times \int_{-a}^{a} f(x) \cos(m_i x + m_i')dx$$

Illustratively, if $f(x) = -C'$, we have

$$M_i = -2m_i C'(2m_i a + \sin 2m_i a \times \cos 2m_i')^{-1} \int_{-a}^{a} \cos(m_i x + m_i')dx$$
$$= -4C' \sin m_i a \cos m_i' \times (2m_i a + \sin 2m_i a \cos 2m_i')^{-}$$

and

$$-C' = -\sum_{i=1}^{\infty} 4C' \sin m_i a \cos m_i'(2m_i a + \sin 2m_i a \cos 2m_i')^{-1} \cos(m_i x + m_i')$$

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Measurement of Stray-Load Loss in Induction Motors

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Synopsis: This paper is written to present test data confirming the accuracy of the reverse-rotation test for stray-load loss[24] in polyphase induction motors. This method is the most convenient yet proposed for direct measurement of stray-load losses in squirrel-cage motors, and it is recommended that it be included in the AIEE Test Code for Polyphase Induction Machines.[27] Proposals for this revision are made.

THE efficiency of an induction motor may be determined by one of several methods. One method is to load the motor to normal load and measure the electric input and mechanical shaft output power. This is the so-called input-output method. Another method, usually termed the segregated-loss method, is to determine each loss separately and to calculate the efficiency from their sum.

The input-output method is the precise method of determining efficiency but is often very difficult to perform. Precise technique[19,31,28] is required, regardless of how the motor is loaded. When input and output are measured, the difference of these two quantities of nearly equal magnitude is the result required. Accuracy is reduced by the subtraction. Often the necessary power supply and loading equipment are not available to load fully large motors under conditions where accurate measurements may be taken.

Consequently, it is very important to have dependable methods available to determine efficiency by the segregated-loss method. Not only is it important to know the sum of the losses, but also, from the designer's point of view, it is important to know the value of each loss. The losses that must be determined are the primary copper loss, the secondary copper loss, the core loss, friction and windage loss, and stray-load loss. The first four of these may be measured quite accurately by comparatively direct methods.

Stray-load loss, however, is more difficult to measure. Before methods were available for direct measurement, stray-load loss often was called the unknown loss to distinguish it from the four components of the total loss that could be measured directly. It is similar to the short-circuit core loss in transformers and synchronous machines and is caused by leakage flux.

It is to be expected that stray-load loss in induction machines could be measured in a manner similar to that used to measure short-circuit core loss in synchronous machines. One member could be excited with direct current of such value to give full-load current in the other member, which would be short-circuited. At the same time the shaft would be driven at normal speed. By measuring shaft input and determining the copper loss in the short-circuited member, the stray-load loss or short-circuited core loss could be calculated.

This method is the one now in the test code for direct measurement of stray-load loss of induction motors. It is very satis-

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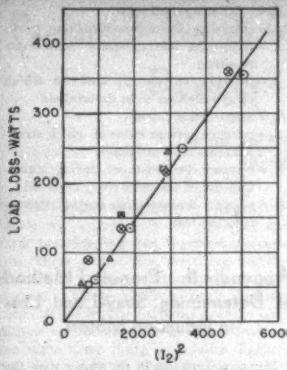

Figure 1. Stray-load loss tests on 25-horsepower 1,800-rpm motor

⊙ Stray-load loss by reverse rotation
⊗ Stray-load loss by dynamometer efficiency test, number 1
△ Stray-load loss by dynamometer efficiency test, number 2
□ Stray-load loss by dynamometer efficiency test, number 3

factory for wound-rotor motors, where the direct current may be applied to the secondary winding, generating normal frequency in the primary winding. However, squirrel-cage motors can be excited only from the primary winding. The secondary copper loss must be measured by applying the equivalent alternating current to the primary winding and measuring the torque at standstill. This test, which is described on page 12 of the "AIEE Test Code for Polyphase Induction Machines," has not proved practicable for factory use.

In 1939, T. H. Morgan, W. E. Brown, and A. J. Schumer presented the reverse-rotation method of measuring stray-load loss.[14] This test is more direct and easier to perform on squirrel-cage motors. Considerable care must be taken to get accurate results by the reverse-rotation method, since the load loss is the difference between measured quantities. However, it is easier to obtain a certain degree of accuracy with this method than with the input-output method because the quantities measured are so much smaller in the reverse-rotation test.

In the discussion following Professor Morgan's paper it was pointed out that the stray-load losses that occur in the stator at fundamental frequency are not included in the test he proposed. Such losses are caused by leakage flux penetrating the conductors, binding bands, finger flanges, and other structural parts.

It is the purpose of this paper to show that, if these losses are measured separately and properly considered in the calculations, dependable and accurate results will be obtained. These losses may be large or small depending on the design of the motor but usually are not appreciable in small motors. However, large motors, rated 500 to 1,000 horsepower and larger, cannot be tested correctly without considering these losses. This is especially true of two-pole motors.

Test Procedure

The reverse-rotation test is performed by applying balanced polyphase voltage to the stator terminals of the motor while driving the rotor at synchronous speed in the direction opposite to that of the rotation of the magnetic field. If the motor is a wound-rotor motor, the rotor should be short-circuited. The mechanical power required to drive the rotor and the electric power input to the stator each is measured. Let W_r represent the electric-power input to the stator and P_r represent the mechanical power required to drive the rotor. W_r includes the following losses:

1. I^2R loss in the stator.
2. Stray losses in all structural parts, conductors, and so forth occurring at fundamental frequency in the stator.
3. Core loss in the stator that occurs at fundamental frequency.
4. One half the losses in the rotor caused by the fundamental flux. Since the rotor is rotating in the direction opposite that of the magnetic field, these losses occur at a frequency twice that applied to the stator. They include I^2R loss, fundamental core loss, and stray losses in the conductors and structural parts in the rotor.

The quantity P_r includes:

1. Stray losses in the rotor and stator caused by tooth-frequency fluxes.
2. One half the losses in the rotor caused by the fundamental flux.
3. Friction and windage losses.

The friction and windage loss may be measured by removing the voltage from the motor terminals and again measuring the mechanical power required to drive the rotor. Let P_f represent this power.

The I^2R loss in the stator, the stray losses occurring in the stator at fundamental frequency, and some fundamental core loss may be measured by applying the same polyphase current to the stator with the rotor removed. Let this quantity be represented by W_s. The core loss under this condition may be slightly different from that during the reverse-rotation test, since the voltage applied will be somewhat different. However, this core loss has been found to be a negligible quantity in either case. The stray loss in the rotor

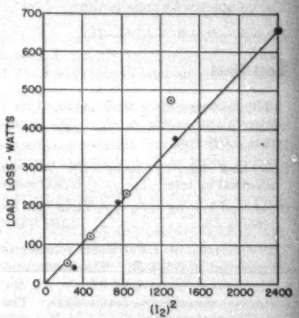

Figure 2. Stray-load loss tests on 30 horsepower 1,200-rpm motor

⊙ Stray-load loss by reverse rotation
• Stray-load loss by dynamometer efficiency test

and stator caused by the tooth-frequency fluxes may be represented by

$$LL_r = (P_r - P_f) - (W_r - W_s)$$

The stray loss in the stator due to the fundamental frequency is represented by

$$LL_s = W_s - I^2R_s$$

where R_s is the d-c stator resistance at the temperature conditions of the test with the rotor removed. This loss is caused by the stator current and is proportional to the square of the stator current. However, that portion caused by the magnetizing current is included in the measurement of the no-load core loss and should be omitted in the determination of stray-load losses. Consequently, this loss should be determined at a value of current,

$$I_1 = \sqrt{I_1^2 - I_m^2}$$

where I_1 represents the primary current when the motor is loaded, and I_m represents the magnetizing current.

It has been shown[13] that the tooth-frequency loss, LL_r, varies with the square of the rotor current. Since the

Table I

Motor	Stray-Load Loss by Dynamometer (Watts)	Stray-Load* Loss by Reverse Rotation (Watts)
A	637	650
B	230	245
C	400	335
D	195	230
E	487	450
F	712	620
G	130	215
H	1,003	800
I	355	520
J	747	670
K	224	350
L	184	157
M	255	260

* Fundamental stator loss was considered to be negligible.

rotor current is approximately equal to I_2, the tooth-frequency loss also should be determined at current I_2.

The reverse-rotation test and the stator-impedance test may be taken at different temperatures. In order that a correction for copper temperature can be made, it is best to keep LL_r separate from I^2R. If R_r represents the d-c resistance at the temperature of the reverse-rotation test, the formula for the tooth-frequency loss becomes

$$LL_r = (P_r - P_f) - (W_r - I_2^2 R_r - LL_2)$$

The total stray-load loss equals

$$LL_t = LL_r + LL_s$$

The completed formula is then

$$LL_t = P_r - P_f - W_r + I_2^2 R_r + 2LL_s$$

Test Data

The following data were obtained on a squirrel-cage motor rated 1,750 horsepower 3,600 rpm.

Stray-load loss by pump-back between identical motors.....11,800 watts

Stray-load loss by reverse-rotation test including LL_2.....13,100 watts

The difference of 1,300 watts represents 0.1 per cent of full load. The fundamental-frequency stray-load loss in the stator was measured as 5,400 watts. The reverse-rotation test as originally proposed neglected the fundamental stator loss, but this test clearly indicates that it must not be neglected. Without this correction, which is twice LL_s or 10,800 watts, the stray-load loss would have been calculated to be 2,300 watts from the test data.

A squirrel-cage motor rated 500 horsepower at 1,800 rpm was tested with the following results:

Stray-load loss by pump-back between identical motors.....2,500 watts

Stray-load loss by reverse-rotation test including LL_2.....2,800 watts

The two methods differ by 300 watts or 0.08 per cent of full load. The fundamental loss in the stator was tested to be 320 watts. Here consideration of the fundamental stator loss is not so important.

The tests that follow were taken before it was thought necessary to consider the fundamental stator loss. However, motors of similar size and design were tested for this loss and were found to have a negligible amount.

Three methods were used to test a wound-rotor motor rated 150 horsepower at 900 rpm. The following values were obtained for rated load.

Stray-load loss by pump-back between identical motors.....615 watts

Stray-load loss by reverse-rotation test (LL_s neglected).....600 watts

Stray-load loss by d-c excitation of rotor.....600 watts

A squirrel-cage motor rated 25 horsepower at 1,800 rpm was tested by reverse-rotation test. Dynamometer efficiency was measured three times. Figure 1 gives the results of these tests. The fundamental stator loss was neglected.

A 30-horsepower squirrel-cage motor, rated 1,200 rpm, was tested by the reverse-rotation method and by dynamometer efficiency. Figure 2 shows the results. Here also, the fundamental stator loss was neglected.

Thirteen motors, all rated 25 horsepower at 1,800 rpm, of the squirrel-cage type were tested by dynamometer efficiency and by the reverse-rotation test. These motors were built by 11 different manufacturers and varied considerably in their characteristics. Table I gives the results.

These data should be considered by examining the error in load loss as a per cent of full load, not as a per cent of the load loss. The probable error in measurement is about the same quantity in watts for a given size motor, whether the load loss is large or small. Consequently, the error expressed as a percentage of full load is a better measure of the value of a stray-load loss test. This is true whether the load loss is determined by pump-back between identical motors, by a dynamometer, by the reverse-rotation test, or by d-c excitation of the rotor.

Conclusion

It is now six years since the publication of Professor Morgan's paper. This seems sufficient time for all concerned to evaluate his method of direct measurement of stray-load loss.

This paper indicates how his method may be brought into agreement with the input-output test by making the test and correction for fundamental stator-load loss in large motors. This correction is unnecessary in testing small motors. With this correction, where necessary, the reverse-rotation test is accurate for all sizes and speeds of motors and is easily performed.

It appears desirable, therefore, to consider Professor Morgan's method for inclusion in the "AIEE Test Code for Polyphase Induction Machines."

Appendix I. Nomenclature

W_r = power input to stator during reverse-rotation test

P_r = power input to shaft during reverse-rotation test

P_f = power input to shaft with no power applied to stator terminals

W_s = power input to stator during stator-impedance test with rotor removed

LL_t = total stray-load loss

LL_r = stray-load loss due to rotation

LL_s = stray-load loss in stator with rotor removed

I_1 = primary current at load for which stray losses are to be determined

I_m = magnetizing current

I_2 = primary current value at which stray-load loss tests are made

R_s = primary d-c resistance during stator-impedance test with rotor removed

R_r = primary d-c resistance during reverse-rotation test

Appendix II. Proposed Method of Determining Stray-Load Loss in Induction Motors

Measure stray loss in the stator with the rotor removed by applying balanced polyphase current to the terminals of the primary winding. The value of watts measured, less the primary I^2R current, is designated by LL_s. This loss should be measured at a value of current I_2 where.

$$I_2 = \sqrt{I_1^2 - I_m^2}$$

I_1 is the primary-load current and I_m is the magnetizing current.

With the rotor and stator assembled, apply balanced polyphase current to the stator terminals. Drive the rotor at synchronous speed in a direction opposite to that of the phase rotation of the stator. Measure shaft input designated by P_r and the stator input designated by W_r. These measurements should be made at the value of current I_2.

Remove the power from the stator and determine the mechanical power required to drive the rotor at synchronous speed in the same direction. Designate this power by P_f.

The stray-load loss is then equal to

$$P_r - P_f - W_r + I_2^2 R_r + 2LL_s$$

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Preferred Practices for Electric Control Devices for Aircraft

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THE devices required for controlling electric equipment on airplanes include pressure switches, thermostats, control relays, contactors, switching mechanisms, and various combinations of these devices. These controls must operate correctly under the extremely severe conditions encountered on airplanes and, at the same time, must be smaller, lighter, and more reliable than similar devices produced for other applications.

In order to design properly to meet the requirements, it is necessary first of all to set up standards which describe accurately the conditions under which the devices must operate. Test equipment is built which simulates these conditions and is used to check the operation of devices in accordance with the standards.

The results of these tests provide additional standards such as electrical creepages and clearances and, in addition, they indicate desirable design features which should be incorporated in devices to make them suitable for operation on airplanes.

It is regrettable that at this late date there are no general standards for electric devices used on airplanes. There are many standards set by governmental agencies for specific devices but these standards are not consistent with those of other agencies, or even with other standards set by the same agency.

The purpose of this paper is two-fold:

1. To suggest that the AIEE set up standards of preferred practices for electric control equipment used on aircraft. A set of standards is included as a sample of the type of standards which are considered necessary.

2. To describe design features which have definite advantages under conditions encountered on aircraft.

Altitude

One of the first requirements for a device which is used on an airplane is that it must operate satisfactorily at the altitudes which will be encountered by the airplane. Not many years ago, an altitude of 25,000 feet was considered the ultimate in airplane performance. The altitude record in 1929 was less than 42,000 feet. Today, we speak of 40,000-foot service ceilings for present-day airplanes and of 50,000-foot service ceilings for airplanes that will be built in the near future. In order that the electric devices of today will operate satisfactorily on the airplanes of tomorrow, standards for altitude should be 50,000 feet.

An altitude of 50,000 feet is equivalent to an absolute pressure of 3.4 inches of mercury. This pressure is readily obtainable with a small vacuum pump. The majority of tests on devices to determine the effect of altitudes can be run on equipment consisting of the compressor from a small household refrigerator connected as a vacuum pump to a bell jar equipped with terminal connections for handling various types of control and load circuits.

The greatest effect of altitude on electric control devices is the effect upon the electrical rating of contacts, due to the increased difficulty of extinguishing an arc at the low pressures encountered at high altitudes.

A large number of tests have been run to determine the effect of altitude upon contact-interruption ratings at various voltages and with various forms of contact mechanisms. Much of these test data have been described in detail in a paper presented by J. S. Rader and L. T. Quill at the Los Angeles meeting of AIEE held in August 1944.[3] From a design viewpoint, the comparison of 12- to 24-volt operation and the advantages of double-break contact construction should be stressed. When most airplanes were equipped with 12-volt systems there was little difficulty in extinguishing arcs, even at high altitude. When airplane voltages were increased to 24 volts, arcing troubles were encountered. Figure 1 shows that a contact break of only $^1/_{32}$ inch will extinguish a 12-volt 40-ampere inductive arc but it will extinguish only four amperes if the voltage is increased to 24 volts.

However, reference to Figure 2 shows that use of double-break contacts practically eliminates the handicap of the 24-volt system. The contact gap for 24 volts with double-break contacts is practically the same as that required for 12 volts with single-break contacts. The close relationship between the curves in Figures 1 and 2 indicates the operation of some physical law or a remarkable coincidence.

The reduction of ratings of contact devices due to altitude is clearly shown in Figure 3. Sea-level ratings must be divided by three to obtain ratings for high altitude. Fortunately the rating curve takes an upward turn at altitudes above those under discussion. The extreme case is the high rating of the vacuum switch.

Another important factor to be considered in high-altitude design work is the necessity for greater creepages and clearances due to lower potential breakdown values at high altitudes. M. J. DeLerno's paper[4] on potential breakdown

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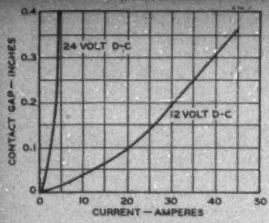

Figure 1. Comparison of single-break contact gaps required for 12- and 24-volt inductive loads at altitudes to 50,000 feet

These curves show conservative ratings for inductance equivalent to motor loads and are about 50 per cent of maximum interrupted test values

at high altitude indicates that high potential tests made at sea level on devices to be used at high altitude should be three times the normal values.

Vibration

Devices should operate satisfactorily under any conditions of vibration encountered on an airplane. However, there still is no definite figure to express accurately the maximum vibration conditions actually encountered on all types of airplanes.

There has been a rule of thumb which states that a device should not be damaged by vibration having simple harmonic motion, with an amplitude of $^1/_{32}$ inch which is equivalent to a total travel of $^1/_{16}$ inch. This vibration should vary in frequency from 5 to 55 cycles per second, with the frequency continuously varying. If the device is not damaged by this vibration for a period of five hours, it is considered that it will not be damaged by the vibration it will encounter during the life of the device. This requirement was amplified by some to such an extent that devices had to operate satisfactorily even under these extreme conditions of vibration. We believe that this was never the intent of the requirement. Many devices are built to operate within certain specified tolerances. Under these extreme conditions of vibration they will not operate within those tolerances. Furthermore, under those conditions they may actually operate incorrectly. It seems that there should be a difference between the values for a shakedown test during which a device will not become inoperative and operational test during which a device should operate within prescribed limits. A shakedown test should be equivalent to an accelerated life test. This principle has been carried out in the new specifications set up by Wright Field covering requirements for 400-cycle apparatus. Standards have been set up which require that a device should not be damaged by vibration for five hours with a $^1/_{32}$-inch amplitude. A second standard for operation requires that a device must operate satisfactorily during vibration of $^1/_{32}$ inch total travel at frequencies from 5 to 55 cycles per second.

Test equipment for checking devices under these conditions of vibration is now readily obtainable from many sources. Some types of testing equipment have been made extremely heavy and rugged to withstand the vibration set up by their own moving masses. This has necessitated fastening of the equipment to large masses of concrete and has made it extremely difficult to measure correctly vibration amplitudes. Other forms of vibration machines are inherently balanced and are, therefore, lighter weight and have longer life. They are particularly well suited for life testing.

Tests on various devices on the vibration machine show the importance of balanced construction. Pivoted parts should have equal masses on each side of the pivot. Furthermore, tests on the vibration machine show that parts should be rigid and, at the same time, have as light weight as possible.

Figure 4 shows an extremely sensitive relay which is equipped with a balanced armature and which is ideally suited for operation under vibration conditions. This is a polarized relay with a dead center position. When no current is applied, the armature is in a central position and contacts are both open. These contacts remain open even if the relay is subjected to vibration of $^1/_{32}$ inch total travel at any frequency up to 60 cycles per second. Then, if the relay is energized by current flowing in either direction, one pair of contacts will close and will stay closed under the same vibration conditions. The amount of power necessary to close the contacts and hold them against this vibration is only one half milliwatt. The design of a relay with such a low-power input, able to withstand such extreme vibrations, would be extremely difficult if the principle of balanced construction were not observed.

Temperature

Temperature conditions encountered by aircraft are far more severe than are encountered in ordinary applications of other devices. The higher an airplane flies the lower the temperature it encounters until it reaches the stratosphere. Then the temperature begins to increase. But at an altitude of 60,000 feet above the equator, the temperature may be as low as 112 degrees Fahrenheit. However, the Army Air Forces, in their winterization program, have set −65 degrees Fahrenheit as the minimum temperature for design requirements.

On the other hand, it has been found advisable to design devices to withstand temperatures as high as 200 degrees Fahrenheit for 48 hours. It is, therefore, necessary that the designs for devices for aircraft be suitable for a total range of 265 degrees Fahrenheit. The main item of interest in covering this wide temperature range is the proper choice of materials to insure correct operation of devices over this temperature range. Tests on pressure switches which had rubber diaphragms showed the differentials might become 20 to 30 times as great when the rubber was stiffened by low temperatures as it would when operating at normal temperatures. On the other hand, pressure switches equipped with metal bellows are practically unaffected by temperature.

In designing devices for aircraft, the kinds of material used should be carefully chosen so that different expansion coefficients of materials will not cause wide variations in operation. A piece of aluminum one inch long will shrink two thousandth's of an inch more than a piece of iron one inch long in going from the top temperature at 200 degrees Fahrenheit to the bottom temperature of −65 degrees Fahrenheit. This change in dimension may be the cause of faulty operation in many devices.

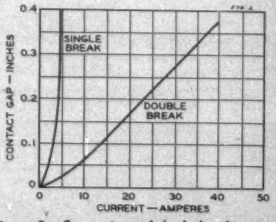

Figure 2. Comparison of single-break contact ratings to double-break contact ratings for 24-volt d-c inductive loads at altitudes to 50,000 feet

These curves show conservative ratings for inductance equivalent to motor loads and are about 50 per cent of maximum interrupted test values

A wide range of temperature makes it essential that any timing devices operating on a thermal principle must be compensated for temperature. This may be done as is shown in Figure 5, by having two pieces of bimetal which oppose each other. Change of ambient temperature increases the forces between the two pieces of bimetal. Heating of one bimetal with relation to the other will operate the contact mechanism after a definite time. Due to the compensation principle used, the timing is practically unaffected by change of temperature.

On the other hand, it should be noted that common forms of timing relays operating on the flux-decay principle are considerably affected by temperature. The curve shown in Figure 6 is representative of the temperature effect upon this

type of relay. Most of the change in timing is due to the increased conductivity of the copper slug at low temperatures. This characteristic should be taken into account in applying timing devices so that the increased timing at low temperatures will not be a source of trouble.

Salt Atmosphere and Humidity

A commonly accepted standard for salt atmosphere is that a device must pass satisfactorily a 200-hour salt-spray test. This is an accelerated test which is generally imposed upon a device after it has satisfactorily passed all other tests. There is considerable difference in opinion as to whether it is necessary for a device to operate satisfactorily immediately after being taken from the salt-spray test, or whether it is permissible to clean the salt off the device and then have it operate satisfactorily. There seems to be no firm standard on this subject. It appears reasonable to set up as a standard that a device must operate satisfactorily after it has been cleaned, following exposure for 200 hours to the salt-spray test. When a

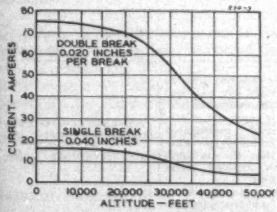

Figure 3. Comparison of 0.020-inch double-break contact rating to 0.040-inch single-break contact rating for 24-volt d-c inductive loads

Contact ratings are approximately 50 per cent of maximum interrupted-current test values. For rating purposes, inductive loads are considered to be motor loads with L/R ratio about 0.03

small electric control which has contacts as part of its mechanism is exposed to the salt-spray test and is left uncovered in the salt spray for a period of 200 hours, it is certain that particles of salt will evaporate out of solution on the contacts. When the device is removed from the salt spray and the salt has thoroughly dried on the contacts, it is quite unlikely that the contacts will operate. If, however, the salt is removed, the contacts should operate properly. The condition of 200 hours of steady exposure to salt spray is an accelerated testing condition which is not actually met in service. It is more intended to prove that the device will not corrode and become inoperable due to corrosion resulting from the salt atmosphere encountered by airplanes operating near the ocean. We, therefore, feel that the above interpretation of the standard is fully justified by the actual application of the devices.

In addition to the salt atmosphere, there is an atmospheric condition of high humidity which often is encountered by devices. This humidity condition is far more severe than has been ordinarily encountered by devices manufactured for use in the United States. In the tropics, it is often possible to have high temperatures and, at the same time, high humidities. In order to simulate this condition with an accelerated test, we have set as our standard for humidity requirements that a device must operate satisfactorily after being subjected to a 95 per cent humidity at 100 degrees Fahrenheit for a period of 168 hours.

The test equipment for salt-spray testing is fully described in Army-Navy Specification AN-QQ-S-91. This type of equipment has been used for some time for corrosion-resistance tests. For the testing of devices under conditions of humidity, an easy way to maintain correct humidity is to place the devices in a bell jar together with certain salts which automatically maintain a correct percentage of humidity. Potassium-sulphate crystals hold a humidity of 96 per cent at 100 degrees Fahrenheit.

In order to design devices which are suitable for uses under the conditions of corrosive atmosphere and humidity, there seem to be three major items which have to be kept constantly in mind. The first of these is that when dissimilar metals are used close together they must be properly chosen so that they are not far apart on the electromotive series or, if they are far apart, they must be properly plated. For instance, a designer who is accustomed to using parts made of brass must be particularly careful to see that they are not fastened directly to aluminum parts, unless the brass parts are plated by a coating such as nickel plate. Secondly, it is essential that all steel parts must be plated with a corrosion-resisting plating or the parts must be made of a type of stainless steel. This does not work an undue hardship on the designer in the case of structures, but it is often difficult to protect properly stampings made from thin spring steel or wire springs made from spring wire having diameters of less than approximately $^1/_{32}$ inch. Ordinary plating methods are very likely to produce faulty springs since the nascent hydrogen produced in the plating process may attack the spring steel and cause hydrogen embrittlement. Reputable spring manufacturers have developed properly controlled techniques for taking care of this condition but it is still an item which must be watched carefully.

One of the most severe effects of humidity on materials is the expansion of plastic parts on which changes in dimension may cause difficulty. Some molded parts are entirely satisfactory for ordinary domestic applications but may change dimensions by as much as $^1/_{64}$ inch per inch when subjected to the extreme humidity conditions encountered by our airplanes. This by no means prohibits the use of molded parts on airplane devices but does warrant extreme care in their use wherever dimensional stability is essential for correct operation. Of course, this condition is even more amplified in the case of fibre parts which will expand two to three times as much as common plastic parts.

Voltage

Designers of aircraft controls have had difficulty in finding out just what the standards of voltage are which must be met by devices when used on airplanes. Normally, the planes of today have 24-volt systems. Actually, this means that the battery furnishes 26.4 volts at full

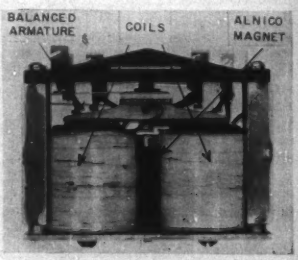

Figure 4. Balanced-armature design of polarized relay operates correctly even under extreme conditions of vibration with only one-half-milliwatt coil input

charge at the battery terminals. When the generator is operating properly, it supplies a regulated voltage of 28.5 plus or minus 0.5 volt at the voltage regulator terminals. A designer, therefore, has a choice of a number of voltages to consider as standard. On the basis of the nominal voltage the standard practice for d-c systems allows ten per cent over and 20 per cent under. Therefore, he could design a device to operate at 26.4 volts maximum and 19.2 volts minimum. This is obviously incorrect since the top voltage may go as high as 29 volts on a properly regulated system. Starting from the maximum voltage of 29 volts and using the same spread of plus ten per cent and minus 20 per cent, we work backwards to a minimum value of 21 volts. This seems like a reasonable spread of voltage and indicates that a device should operate satisfactorily at voltages as low as 21 volts and should not overheat at voltages as high as 29 volts. However, it is possible that the generators may be shot away and all important devices must operate satisfactorily on the battery voltage.

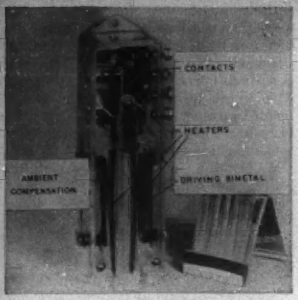

Figure 5. Thermal timing relay with ambient-temperature compensation

Sample in transparent housing

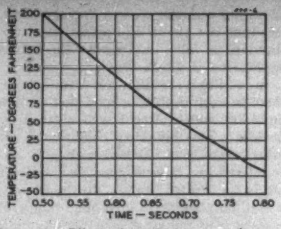

Figure 6. Effect of temperature on dropout time of flux-decay relays

This indicates that there may be a minimum voltage of 19 volts. However, the batteries are probably highly overloaded when generators are inoperative, so it seems advisable that an even lower value should be used. A standard of 18 volts seems reasonable thereby allowing a one-volt additional safety factor over the 19 volts given above. However, it should be noted that some of the Air Corps standards call for correct operation at 20 volts.

A standard stating that devices must operate correctly at 18 volts is incomplete unless temperatures are also taken into consideration. A device which may function properly at 18 volts with ambient temperatures of 70 degrees Fahrenheit may not operate at 18 volts at 200 degrees Fahrenheit. And even though it may operate at 18 volts at 200 degrees Fahrenheit for a short period of time, its own self-heat over a longer period of time may make it inoperable at the same values. Fortunately, the temperature of 200 degrees Fahrenheit cannot exist for any long period of time after the airplane is in operation so the possible condition of operation for an extended period of time at temperatures above 70 degrees Fahrenheit may be assumed to be nonexistent. This is the basis of the standard that devices must operate correctly at 18 volts and 200 degrees Fahrenheit with no self-heating and at 18 volts at 70 degrees Fahrenheit with full self-heat.

Conclusions

Lieutenant Colonel Holliday, head of the electrical equipment laboratory at Wright Field, has emphasized the fact that a device which is not completely reliable has no place on an airplane. At the same time, he points out that weight is the prime consideration in choosing between two devices which are equally reliable.

In order to meet both of these requirements it is essential that the designer of devices for aircraft must have clear-cut definitions of the requirements of devices for aircraft in the form of design standards. There are no such standards at the present time.

Should not the AIEE and the National Electrical Manufacturers Association fill this need by setting up standards of preferred practices for electric devices used on aircraft? As a concrete foundation for such a program the following suggestions are offered for discussion and consideration as standards to cover electric control devices.

Appendix. Standards for Electric Control Devices Used on Aircraft

A. Devices must operate satisfactorily under the following conditions or any combination of these conditions.

1. Acceleration to ten *g*.
2. Altitudes to 50,000 feet.
3. Vibration at amplitude of 0.015 inch with frequencies of 0 to 55 cycles per second
4. Temperatures from —70 degrees Fahrenheit to +70 degrees Fahrenheit for continuous operation.
5. Voltages from 18 to 29 volts for 24-volt systems.

B. Devices must withstand the following conditions without being damaged. If operating characteristics are affected to the point where the device does not operate satisfactorily it will be considered damaged.

1. Vibration for five hours in each of the two worst airplanes at an amplitude of 0.030 inch and with frequencies from 0 to 55 cycles at normal room ambient temperature.
2. Temperatures from —70 degrees Fahrenheit to 200 degrees Fahrenheit for 48 hours at the worst temperatures.
3. Humidity of 95 per cent at 100 degrees Fahrenheit ambient temperature for 168 hours with rated coil voltage applied from coil terminal to ground.
4. Salt spray for 200 hours. Salt crystals may be washed off before rechecking operation.
5. High-potential test:

Rated Voltage	High Potential A-C Rms Volts Applied for One Second: Sea Level	High Potential A-C Rms Volts Applied for One Second: 50,000-Foot Altitude
Up to 50 volts direct current	600	250
Up to 208 volts direct current	3,000	1,000

C. Ratings

1. Magnet coils.

Must pick up at 200 degrees Fahrenheit ambient temperature with no self-heat in coil at 18 volts for 24-volt system.

Coil temperatures must not exceed 325 degrees Fahrenheit with maximum volts and 200 degrees Fahrenheit ambient temperature with device mounted on aluminum plate in accordance with reasonable design practice.

2. Contact ratings.

Devices with motor ratings must be able to make and break six times their normal rating with $L/R = 0.03$.

D. Spacings (inches)

	Potential in Volts: 0 to 30	Potential in Volts: 31 to 300
Between any uninsulated live part and an uninsulated part of opposite polarity,* uninsulated grounded part other than the enclosure or exposed metal part: Through air	1/16	1/8
Between any uninsulated live part and an uninsulated part of opposite polarity,* uninsulated grounded part other than the enclosure or exposed metal part: Over surface	1/8	1/4
Between any uninsulated live part and the walls of a metal enclosure	1/8	1/4
Between wiring terminals	1/8	1/4

A barrier of 1/32-inch-thick insulation may be used in lieu of these spacings.

* Parts of opposite polarity are those which may be so connected in a circuit that a direct connection between the parts would produce a short circuit.

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Tracer-Controlled Position Regulator for Propeller Milling Machine

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IN a companion paper by Rutemiller and Morton[1] the electrical control of an automatic machine for milling ship propellers up to 24 feet in diameter is described. The outstanding features of this machine, which is illustrated in Figure 1, are the speed and accuracy with which it can generate the desired blade contours in conformity with scale models. These features permit enormous savings in time over previous methods of propeller machining. This superior performance is made possible largely by the use of two tracer-controlled regulators to control the positioning of milling cutters which machine both faces of the blades simultaneously. It is the purpose of this paper to describe the design features and performance characteristics of the regulators and to indicate by means of a typical stability calculation in an appendix some of the theoretical considerations involved in their development. Although the regulating system described was designed specifically for the propeller milling machine, it may be used, with some modifications, in other machine-tool applications, as well as in other fields.

General Description

The control required for contour following comes under the classification of position regulators and presents a much more difficult problem than most other types of regulators, such as speed governors or electric voltage or current regulators. In position regulators a follow member not only must accelerate at the proper rate and move at the right speed, but also must be in the correct position. In an electric system using a fixed-field motor whose armature is supplied with variable voltage from a generator, the current must be controlled for proper acceleration, the voltage must be regulated for proper speed, and the accumulated motion must at every instant be such as to position the follow member accurately. It should be apparent, therefore, that such regulators are of necessity more involved than most other regulators.

In the propeller milling machine, two identical position regulators are needed—one normally being used to control the suction-face drive motor, and the other the pressure-face drive motor. As illustrated in Figure 2, each regulator consists essentially of a standard variable-voltage drive with the exciter for the main generator energized by a single-stage d-c amplifier which derives its positioning stimulus from a Silverstat tracer unit. The unidirectional output of the exciter is applied to the generator field in series with an independent constant potential so as to obtain a drive-motor rotation that is continuously variable from a maximum in one direction through zero to a maximum in the opposite direction. Each motor drives a small saddle carrying the associated tracer unit and also a large saddle carrying one of the two milling cutters.

A detailed description of the operation of the machine is given in the companion paper already referred to. Consequently, the following brief explanation will suffice to describe the functioning of the regulators. As the model table rotates relative to the tracer unit, the tracer probe will be deflected as it traverses the model. This causes a corresponding deflection of the tracer Silverstat,[2] resulting in a proportional change in the Silverstat voltage. This voltage change is amplified by the amplifier and exciter and results in a change in generator voltage which causes the drive motor to move the tracer saddle in the direction to return the tracer probe and Silverstat to their original positions, relative to the saddle. Errors are minimized and hunting is prevented by circuits which are described later.

The ratio of the tracer-saddle speed to the cutter-saddle speed is adjusted by means of gearing to equal the scale ratio of the model. Also the work arbor supporting the propeller is rotated in unison with the model table. Consequently, the milling cutters move proportionately across the blade faces in contours similar to those being traced by the corresponding probes. The Silverstat steps are sufficiently small and the stability of the regulating system is sufficiently great to produce continuously smooth and stepless motion of the cutter saddles.

Following each cutting stroke the propeller blade and models are returned automatically at high speed to the starting position, preparatory to the next cut. During this return traverse the main saddles attain velocities several times the normal cutting speed, and, although there is no requirement for accurate following during the return stroke, because the cutting tools are withdrawn from the work, it is necessary that the regulators retain control throughout this interval to avoid severe transient disturbances during reversals of direction at the ends of the strokes.

The Tracer Unit

The tracer unit is illustrated in Figures 3 and 4. It consists essentially of a small Silverstat operated by a double-lever system. These elements together with the Silverstat resistors are compactly assembled within a cylindrical steel case. A probe whose shape conforms to that of the cutting tool is mounted on the tapered nose of the primary lever.

The ratio of the lever system is adjustable so that the motion of the probe required to produce full Silverstat deflection can be made to correspond approximately to the ratio of the size of the model to that of the propeller being machined. This adjustment in the tracer sensitivity provides means for maintaining the stiffness* of the regulator constant as the model ratio is changed. In other words, when a particular size of model is used, the absolute magnitude of the error is independent of the model ratio, and a 24-foot propeller can be machined with no greater absolute error than a ten-foot one. Since this adjustment affects only the magnitude of the error and does not of itself determine the model ratio, it does not need to be continuous. Accordingly, four positions of the ratio-adjusting pin, corresponding to blade-to-model ratios of 2, 3, 4, and 5, provide adequate range.

The spring and gravitational forces acting on the levers are such that the maximum force on the probe need never exceed two pounds. Thus, with probes of reasonable weight the force exerted on the model is sufficiently low to permit the use of even moderately soft materials such as plaster or soft wood. Ball-bearing pivots provide definite fulcrums with minimum friction for both levers.

A pair of contacts built into the tracer unit serves as a limit switch to shut down the machine when the Silverstat operating lever is deflected beyond its normal range. This feature protects the propeller blade, the tracer unit, and the machine, from damage due to mechanical or electrical failures. A time-delay relay in the limit-switch control circuit prevents shutdown during minor transient conditions which result in only moderately excessive accelerations. During these transients

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* The stiffness of the regulator is defined as the force developed on the main saddle by unit main-saddle displacement.

Figure 1. A general view of the propeller milling machine

The model table is in the left foreground. The propeller mounted on the work arbor is about 12 feet in diameter

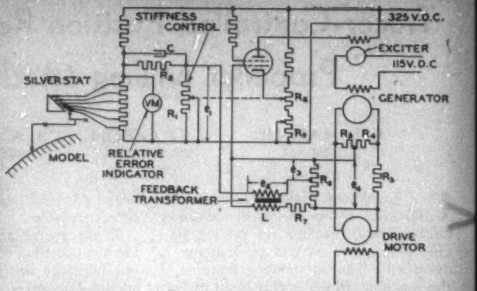

Figure 2. Schematic wiring diagram of the regulating system

damage to the tracer is prevented by adequate overtravel in the lever system.

The Regulator Circuit

Because of time delays inherent in the regulating system a stable regulator capable of only mediocre accuracy can be realized by applying only the Silverstat positioning stimulus to the amplifier input. Sustained oscillations in this simple low-accuracy regulator would be prevented by the inherent damping of the motor-armature circuit. The maximum practical stiffness, and hence the accuracy, of such a system is restricted to relatively low values by fundamental design limitations on the ratio of motor-circuit damping to system inertia and also by the time delays which have the effect of introducing phase shifts that reduce the effective damping of the system. Any attempt to increase the regulator stiffness to improve the accuracy would result in hunting. In the system illustrated in Figure 2 there are three principal time delays: namely, the exciter-field delay, the generator-field delay, and the motor- and generator-armature-circuit delay. Consequently, in order to obtain a regulating system with adequate stiffness to insure high accuracy and at the same time provide sufficient damping to insure rapid decay of free oscillations, it is necessary to introduce strong antihunting influences which will now be described.

In reference to Figure 2, the voltage e_1 appearing across the sensitivity or stiffness-adjusting rheostat R_1 is derived from the Silverstat and has an average value corresponding to the normal zero-error position of the tracer probe. At this normal operating point half of the Silverstat resistance is short-circuited out. Variations from this average voltage value, corresponding to displacement of the probe from its zero-error position, can be considered as made up of two components. One of these is the drop due to the component of current which flows through R_3 and is proportional to the probe deflection or positional error. This component constitutes the positioning stimulus for the regulator. The other component is due to the part of the current which flows through the capacitor C. By making R_1 small compared to R_3, and by proper choice of the value of C, this component can be made proportional to the rate of change or first derivative of the probe displacement. It is well known[2,3] that the inclusion in the input to a regulator of a stimulus proportional to the rate of change of the quantity being regulated exerts a powerful stabilizing effect. When the tracer probe is deflected from its normal position this component of voltage appears ahead of the positioning stimulus. Thus a large restoring force is produced which tends to correct for the error before it can attain its maximum value. For this reason this component may be considered as anticipating the positioning voltage, and the circuit comprised of R_1, R_3, and C therefore is referred to as an anticipator circuit. Because it is not feasible to make R_1 negligibly small compared to R_3, the anticipator does not give perfect differentiation, with the result that an additional small time delay acting upon the anticipator output is introduced into the regulating system. This effect is shown analytically in the appendix.

A further stabilizing voltage, e_2, is obtained from the feedback transformer connected into the generator–motor-armature circuit. The bridge circuit consisting of R_5, R_4, R_3 and the motor-armature resistance are balanced so that the voltage across R_4 is strictly proportional to the back electromotive force of the motor and independent of load and accelerating currents. Since the back electromotive force is proportional to speed, this voltage is thus proportional to the output velocity. The time constant L/R_7 of the primary circuit of the transformer is made low so that the primary current is essentially in phase with the voltage across R_4 and the output velocity. The transformer secondary voltage e_2 is proportional to the rate of change of the primary current and hence is proportional to the output acceleration. This voltage is applied to the amplifier input with a polarity such that the torque due to it opposes rapid acceleration of the drive motor. It is therefore antihunting in its effect. Because it is not feasible to make the time constant of the transformer primary circuit negligibly small, the differentiation of velocity to obtain acceleration is not perfect, and the consequence here also is the introduction of another small time delay, acting in this case only upon the acceleration component of the amplifier input voltage.

With the regulator input voltages described thus far, it is possible to increase the stiffness to a point where the positioning accuracy at very low speeds is more than adequate. However, when the drive motor is running at some constant speed, the steady-state excitation required by the main generator must be produced entirely

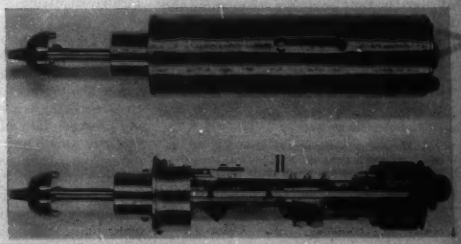

Figure 3. The tracer units

The lower unit is removed from its cylindrical housing

Table I

Machine Constants	Accuracy Constants	Stability Constants
$M = 1.2 \times 10^4$ lbs per (ft per sec^2)	$s = 60 \times 10^4$ lbs per ft	$m = 10.8 \times 10^4$ lbs per (ft per sec^2)
$r = 2.7 \times 10^3$ lbs per (ft per sec)	$r_0 = 2.5 \times 10^4$ lbs per (ft per sec)	$T_a = 0.5$ sec
$T_1 = 0.01$ sec	$k_1 = 8$	$T_t = 0.02$ sec
$T_2 = 0.7$ sec		
$T_3 = 0.05$ sec		

by the positioning voltage. This means that when the motor is running at top speed the Silverstat must be deflected by the probe far enough from the mid-position to produce full excitation of the generator. In other words a high output speed can be obtained only at the expense of a proportional deviation or error in the tracer probe position, and at top speed this error may be several times the normal acceleration error.

It is the function of the voltage e_3 to minimize these errors proportional to speed. This voltage being part of the drop across R_4 is proportional to the output velocity and is applied to the amplifier input in series with e_1 and e_2 in such a direction as to tend to maintain the output velocity which produced it. Most of the main generator excitation required to produce the output speed is thus provided by e_3, relieving the Silverstat of the major portion of this duty. By this means the velocity error is reduced to a small fraction of what it otherwise would be. The portion of the velocity excitation provided by the Silverstat is just sufficient to insure that the tracer unit retains control of the regulator. Instead of improving the stability of the regulator, however, the feedback for velocity-error correction has exactly the opposite effect. Fortunately though, the reduction in damping is small, and it is readily compensated for by a slight increase in the derivative component of the anticipator-circuit output voltage.

The Amplifier

The use of a vacuum-tube amplifier greatly simplifies the attainment of adequate anticipation, acceleration feedback, and velocity-error correction with circuit components of small physical size and low power consumption. Its almost infinite input impedance permits a wide flexibility in circuit arrangement and makes it possible to eliminate completely undesirable loading of the anticipator circuit by the feedback circuits and vice versa. A further advantage of the amplifier is that it permits the use of very low-wattage Silverstat resistors, making it feasible to mount these within the limited space inside the tracer housing, thus avoiding a large number of electric connections to the tracer unit.

Although only a single tube is indicated in Figure 2, there are actually three tubes connected in parallel. This improves the reliability of the equipment, since the regulators still will operate with somewhat greater error on only two tubes. The tubes, which are of a standard radio type obtainable in any radio shop, are very conservatively loaded so as to insure a long useful life.

A potentiometer R_4 in the cathode-biasing circuit is ganged to the stiffness control R_1 for the purpose of compensating for the change in average drop across R_1 as the stiffness of the regulating system is varied. This makes it possible to change the regulator stiffness without causing any disturbance in the system. Control R_9 is used to adjust the regulator to the center of its range during the setting-up process.

A voltmeter connected across the Silverstat is calibrated in terms of relative error and provides a means of constantly checking the operating condition of the regulator and the accuracy of the milling operation. One of these instruments is located at the control station for each of the two regulators. A vernier centering adjustment, not indicated in the schematic diagram, but connected in series with R_9, is mounted alongside the relative-error indicator on the control pedestal. This serves as a relative-error control and may be used by the operator, if desired, to "monitor" the error during the milling strokes. It also facilitates adjustment during the setting-up operation and provides a means of correcting for possible drifting during the initial warming-up period.

Performance

The performance of the propeller-milling machine as a whole is capable of greatly exceeding the specification requirement of 200 square inches of blade surface milled per hour. This is due both to the inherent cutting capacity of the machine and to the ability of the regulators to maintain a high degree of accuracy at speeds higher than needed. A practical cutting speed for face milling is of the order of 30 inches per minute, and at this speed the regulators hold the accuracy to better than ± 0.004 inch at the work. During the high-speed return stroke the velocity reaches 100 inches per minute and the corresponding error is of the order of ± 0.012 inch. As mentioned previously there is no necessity for maintaining high accuracy during the return stroke so that the latter figure has no particular significance in the operation of the machine. It is indicative, however, of the capabilities of the regulators.

The rates of acceleration and deceleration at the ends of the strokes are limited to values of the order of ten inches per minute per second, and during these intervals the error is held to well within the specification requirement of ± 0.020 inch.

Conclusion

In designing the regulators much consideration was given to features which insure reliability and ease of operation. No unusual skill is required either to operate or to service the equipment.

Although the regulating system described was developed specifically for the propeller milling machine, the fundamental principles involved are of such a general nature that they will find useful application in a wide variety of regulator problems.

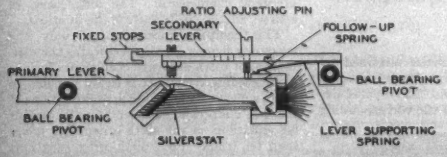

Figure 4. Schematic diagram of the tracer mechanism

Appendix I

The Anticipator

If we refer to Figure 2, the ratio of e_1 to the Silverstat voltage in operational form is

$$\frac{R_1}{R_1 + \dfrac{R_2/C\rho}{R_2 + 1/C\rho}} = \frac{(1+T_a\rho)/(k_1+1)}{1+T_a\rho/(k_1+1)}$$

where

$T_a = R_2C$ = the anticipator time constant
$k_1 = R_2/R_1$
ρ = the differential operator d/dt

It is apparent from this expression that the anticipator output contains two components, one proportional to the Silverstat voltage, and one proportional to the rate of change of this voltage. Both components are delayed, however, as indicated by the time-delay operator[2] $[1+T_a\rho/(k_1+1)]$.

Any departure in e_1 from its average value is due to a displacement of the main saddle from its correct position and results in a force on the saddle tending to reduce the displacement. The appearance of this force, however, is subject successively to the delays of the exciter field, the generator field,

and the generator–motor-armature circuit. The expression for the force due to e_1 in terms of the displacement x is thus

$$F_s = \frac{s(1+T_a\rho)x}{(1+T_1\rho)(1+T_2\rho)(1+T_3\rho)[1+T_a\rho/(k_1+1)]} \quad (1)$$

where the proportionality constant s is the regulator stiffness, and T_1, T_2, and T_3 are, respectively, the three delays previously listed.

Acceleration Feedback

The feedback transformer voltage may be written as

$$e_4 = k_2 L p i = \frac{k_2 L p e_4}{R_1 + Lp} = \frac{k_2 T_1 \rho e_4}{1+T_1\rho}$$

where i is the primary current, k_2 is the transformer ratio, and T_1 is the primary time constant L/R_1. The voltage e_2 is thus proportional to the rate of change of e_4 and is delayed by the time lag of the transformer primary circuit. Since e_4 in turn is proportional to the output velocity or rate of change of displacement, e_2 is proportional to the second derivative of displacement or acceleration. The voltage e_2 also results in a force on the main saddle which is likewise delayed by the times T_1, T_2, and T_3. If we follow the foregoing reasoning, this force, which tends to reduce the acceleration, may be expressed in terms of the displacement as follows:

$$F_a = \frac{mp^2x}{(1+T_1\rho)(1+T_2\rho)(1+T_3\rho)(1+T_4\rho)} \quad (2)$$

where m is the force per unit acceleration and has the dimensions of a mass.

Velocity-Error Correction

In a similar manner the force due to the velocity-error-correction voltage e_3 may be written as

$$F_v = \frac{-r_v\rho x}{(1+T_1\rho)(1+T_2\rho)(1+T_3\rho)} \quad (3)$$

where r_v is the force per unit velocity having the dimensions of damping. The negative sign in equation 3 signifies that the damping is negative or that the force F_v is tending to maintain the velocity ρx rather than to reduce it.

Characteristic Equation

The three forces acting on the saddle due to regulator action are opposed by the inertia of the mechanical system and the electrical damping of the generator–motor-armature circuit. The appearance of the latter opposing force, however, is delayed by the armature-circuit time delay T_3. Expressed algebraically the relationship is

$$-Mp^2x - \frac{rp x}{(1+T_3\rho)} = F_s + F_a + F_v \quad (4)$$

where r and M are, respectively, the slope of the speed–force curve and the mass of the mechanical system, both referred to the saddle. Substitution of equations 1, 2, and 3 in this equation, and reduction of the right-hand side to a common denominator give the following as the characteristic equation of the complete regulator system:

$$-Mp^2 - \frac{rp}{(1+T_3\rho)} = \frac{s(1+T_a\rho)(1+T_c\rho)+mp^2[1+T_a\rho/(k_1+1)]-r_v\rho[1+T_a\rho/(k_1+1)](1+T_4\rho)}{(1+T_1\rho)(1+T_2\rho)(1+T_3\rho)(1+T_4\rho)\times[1+T_a\rho/(k_1+1)]} \quad (5)$$

The constants M, r, T_1, T_2, and T_3 are fixed by the design of the rotating machines,* and constants s, r_v, and k_1 are determined by the accuracy requirements of the regulator. The problem is then to determine values of m, T_4, and T_5, which will result in stable operation with a high rate of decay of free oscillations. A typical set of values is given in Table I.

By substituting these values into equation 5, clearing of fractions, collecting terms, and dividing by the coefficient of p^5, the following equation is obtained:

$$p^5 + 189.3p^4 + 11{,}400p^3 + 268.5\times10^4p^2 + 380.7\times10^4p^3 + 314.6\times10^6p^2 + 67.96\times10^8p + 12.97\times10^7 = 0 \quad (6)$$

The approximate factoring of this equation by the method described in Appendix II is

$$(p+16.2)(p+63.94)(p+95.0)(p^2+2.16p+5.58)(p^2+12.04p+235.4) = 0 \quad (7)$$

The three linear factors in equation 7 represent nonoscillatory motions of the saddle of the form $x = x_0\epsilon^{p_1 t}$ where p_1 is the root of the appropriate factor. The quadratic factors of the form $p^2+\beta p+\gamma$ correspond to oscillatory motions of the saddle which may be represented by the general equation

$$x = \epsilon^{-\Delta t}(A\cos 2\pi f t + B\sin 2\pi f t)$$

where f is the frequency of oscillation and Δ is the decrement. In terms of the trinomial coefficients β and γ,

$$f = \frac{1}{2\pi}\sqrt{\gamma - \beta^2/4}$$

and

$$\Delta = \beta/2$$

The fractional decay per cycle is given by

$$(1-\epsilon^{-\Delta/f})$$

The oscillation frequencies obtained by this means from the two quadratic factors in equation 7 are 0.336 and 2.24 cycles per second, respectively, and the corresponding rates of decay are 96 per cent per cycle and 93.1 per cent per cycle. These rates of decay represent very high damping. If either of these figures were smaller (of the order of 60 per cent or less) it would be necessary to change one or more of the stability constants listed previously and repeat the solution of the characteristic equation. If even the optimum values of the stability constants still yield too low a rate of decay, it is necessary to reduce the regulator stiffness and accept the correspondingly lower accuracy.

* The mass of the saddle is negligible compared to the equivalent mass of the drive motor.

Appendix II

In the solution of high-order linear equations such as equation 6 in Appendix I, the means of finding linear factors by Horner's method or by successive trials using synthetic division are well known. The determination of quadratic factors which represent complex roots presents greater difficulty. A form of synthetic division for quadratic factors was devised by one of the authors for facilitating rapid approximation by successive trials and is shown in this appendix. It was found later that the method was given by M. Liwschitz, formerly with the Westinghouse Electric and Manufacturing Company, in an unpublished report.

Equation 6 after depression by the removal of the three linear factors becomes

$$p^4 + 14.2p^3 + 267p^2 + 575p + 1{,}317 = 0$$

The method is best illustrated by performing the long division by one of the actual quadratic factors.

$$\begin{array}{l|l}
p^4+14.2p^3+267.00p^2+575p+1{,}317 & p^2+2.16p+5.58 \\
p^4+2.16p^3+5.58p^2 & p^2+12.04p+235.4 \\
\hline
12.04p^3+261.42p^2+575p & \\
12.04p^3+26.02p^2+67p & \\
\hline
235.4p^2+508p+1{,}317 & \\
235.4p^2+508p+1{,}317 &
\end{array}$$

In the foregoing, the important figures are underlined. The process is greatly simplified by tabulating only these figures as follows:

1	14.2	267.0	575	1,317	2.16+5.58
		5.58	67	1,317	
	2.16	26.02	508		
1	12.04	235.4	...	...	

The upper of the two rows under the dividend coefficients are the successive products of the differences by the last coefficient of the divisor. The lower of the two rows are the successive products of the differences by the middle coefficient of the divisor. The differences are obtained readily by subtracting two numbers simultaneously from the dividend coefficients. The differences, of course, are the coefficients of the quotient.

This compact tabulation of only the necessary figures greatly facilitates the estimation of more accurate coefficients for use in succeeding trials. It is easily possible to make sufficiently accurate approximations of the two unknown coefficients in the divisor for equations of the sixth order with fewer than ten trials. For fourth-order equations

Application of Electric Equipment for Ship-Propeller Milling Machine

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THE ship screw propeller, introduced a little over a century ago, is now used almost universally.[1] Large high-speed passenger and naval vessels of the present day use propellers as large as 22 feet in diameter. These screws must transmit very large amounts of power which causes them to erode and pit rapidly. Erosion and cavitation can be minimized and the efficiency of power transmission increased by the use of smooth accurately finished blades.

The methods used in finishing ship propellers did not keep pace with the art of machining metals and have been a laborious time-consuming job. The excess metal that had to be removed from the rough casting to produce the desired contour was taken away by hand chipping, grinding, and polishing. The large size and cost of a suitable machine tool undoubtedly discouraged its early development. The first attempts were made about 17 years ago by using modified planers and shapers arranged to generate a helix. In 1937 the Morton Manufacturing Company designed and built a special machine for shaping the pressure face side of propeller blades, and two additional machines of this design have been built since.[2] This machine generates the helix through the action of pitch gears much like a screw-cutting lathe. It is not capable of machining the back or suction-face side of the blade, because this surface is not a true helix. Furthermore, it cannot be used on pressure-face sides of blades on which the pitch is not constant from hub to tip.

The machines just described are limited in their application, and the need for a machine that would generate any contour accurately and quickly was increased by the rapidly expanding ship-building program. In 1940 the Morton Manufacturing Company and the Westinghouse Electric and Manufacturing Company undertook the development of such a machine for the United States Navy.

The general arrangement of the machine is shown in the side elevation and plan view, Figure 1, and in the picture of the final installation, Figure 2. The machine is equipped with two cutting heads so that it can be arranged to operate on both sides of a blade simultaneously, thus speeding up the operation and equalizing the pressure of the cutters and reducing the deflection of the work. This arrangement is clearly shown in Figure 3.

The machine is equipped with 11 motors and three motor generator sets. Practically all of these motors operate in a definite sequence when the machine is performing in an automatic cycle. Full magnetic control is provided for all motors.

Position Regulators

The machine is of the form-following type, that is, one that reproduces the contour of a pattern or model in the metal of the propeller casting. This provides for the machining of any contour on either side of the blade and the machining of any number of propellers with either right- or left-hand pitch from the same model. Since all blades on a given propeller are duplicates, a pattern of only one blade is required, and the propeller is indexed for each succeeding blade.

The models are made of some soft material such as wood, so that they can be made easily by hand. Therefore, the form-following device must apply only a very small pressure to the model. Because of the size of the work, it is desirable to use reduced-size models. Machines of the pantograph type have been built for machining airplane propellers, but the limitations of pressure and the extreme complication of a magnifying pantograph for a machine of this size make such an arrangement impractical. A position-regulating system of the servo type, therefore, is used on this machine.

The accuracy of the machine depends primarily upon the position regulators, and the speed of operation is determined by their ability to follow changes in contour rapidly.

The regulators used on this machine are entirely electrical. They control the speed of the saddle-feed motors from 1,000 rpm forward to 1,000 rpm reverse without any apparent loss of control in the region around zero speed. These regulators are described in another paper.[3]

Cutter Drive

The cutters are driven by adjustable-speed constant-voltage d-c motors, which provide the speed adjustment that is necessary to suit cutters of different diameters. The motors are reversed by manually operated switches on the control panel so that cutters of either hand can be accommodated. The magnetic controllers do not provide dynamic braking, as it is desirable to have the cutters rotate from the momentum of the drive in case of a voltage failure so they will cut themselves clear.

Relieving Mechanisms

The cutter saddles are each provided with relieving mechanisms that move the cutters clear of the work during the return stroke and into position for cutting during

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as illustrated, four or five trials usually suffice, making the method more rapid than the usual Ferrari-Cardan method. A further advantage over the latter and other more or less formal methods is that there is no chance of carrying an error through the complete solution since each trial is a check on the preceding one.

The number of trials required is reduced, of course, if one can start with coefficients close to the final values. A quick and convenient first approximation to the correct value of the last coefficient of the divisor is obtained by factoring the original equation with the odd-powered terms omitted. For the example given the expression

$$p^4+267p^2+1{,}317$$

is factored approximately into

$$(p^2+5)(p^2+260)$$

giving either 5 or 260 as one coefficient of the first trial divisor. This method is exact if the damping in the system is zero, in which case the odd-powered coefficients are absent to begin with. The approximation is quite good, however, for dampings as great as 50 per cent of critical.

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the cut stroke. These mechanisms are driven by compound-wound d-c motors provided with full magnetic reversing control, in order that they will operate in the proper sequence during the automatic cycle.

At the beginning of the cutting stroke, the cutter is positioned with respect to the work by this mechanism. This positioning must be consistent and accurate. The relief-drive motors drive the cutter saddles against a positive stop, at which time the motor stalls. The mechanism is self-locking in this position, and the motor is de-energized by a timing relay.

Ram-Feed Drive

The ram-feed motion, that is, the motion of the cutter radially along the blade is driven by a constant-speed constant-voltage d-c motor. This motor provides movement at traverse speeds for setting up the machine and also movement in definite increments to position the cutter into a new path for each successive cut during automatic operation.

This motor is controlled by a reversing dynamic-braking controller which is governed by a measuring relay. The measuring relay is a device that measures motor revolutions and stops the motor after a definite movement has been accomplished. The increment of movement is adjustable, thus providing a means of adjusting the amount of feed for each stroke. This device, when operating in conjunction with a properly designed controller, consistently can measure increments of one-half motor revolution and can then be adjusted to give any increment of movement up to 20 revolutions.

Saddle-Feed Drive

The saddle-feed screws are each driven by adjustable-voltage d-c drives. These drives are controlled by the position regulators when the tracers are in operation. They are provided with full-magnetic reversing regenerative-braking controllers so that they may be operated from push buttons at high or low fixed speeds for setting-up purposes.

The entire speed range of these motors is obtained by generator voltage control. Consequently, the voltage impressed on the motor armature is an approximate measure of the saddle speed. Voltmeters are provided to indicate this voltage at all times; these are calibrated in terms of saddle speed in inches per minute and provide the operator with a continuous indication of the cutter saddle speed.

Work-Arbor and Model-Table Drive

The work arbor and model table are coupled together mechanically, and, while their relative position may be changed for indexing the blades, they are always moved as a unit during the machining operation.

This is the primary feed motion. When the model table is rotated by the work-arbor motor, the movement of the model changes the position of the probes from their neutral or center position, thus causing the saddle-feed motors to move in the proper direction and at the proper speed to bring the tracer probes back to the center position by moving the tracer saddle. The cutter saddles also are moved a proportionate amount since they are driven by the same motor. Models of different ratios are accommodated by changing the gear ratio between the cutter and tracer saddle; thus the rate of work-arbor rotation controls the rate of motion of the saddles.

There is a certain maximum rate of acceleration that can be accommodated by the position-regulating system. The work-arbor drive is arranged to provide controlled acceleration and retardation so that the ability of the regulator system is not exceeded. The rate of acceleration is controlled by a motor-operated rheostat that is driven by an adjustable-speed d-c motor. This rheostat controls the fields of the work-arbor motor and its associated adjustable voltage generator.

On most machine tools, it is desirable to maintain a certain optimum surface cutting speed. This speed depends upon the size and type of cutter and the material being machined and the geometry of the machine. The construction of this machine is such that the surface speed of the cutter across the work depends primarily upon two variable factors: the pitch of the blade which may vary from six to 30 feet, and the radius of the cut which may vary from one to 12½ feet. The work-arbor drive, therefore, must provide an adjustable-speed range in excess of 60 to one.

Since the work-arbor drive is the primary feed motion, it must be stable at any operating speed over its entire speed range. This means that the speed regulation with changing loads must be practically flat over the entire speed range.

The Rototrol regulated adjustable-speed drive was selected for this motion, because it provides all of these features.[4,5]

The work-arbor motor also may be operated from jogging or inching push

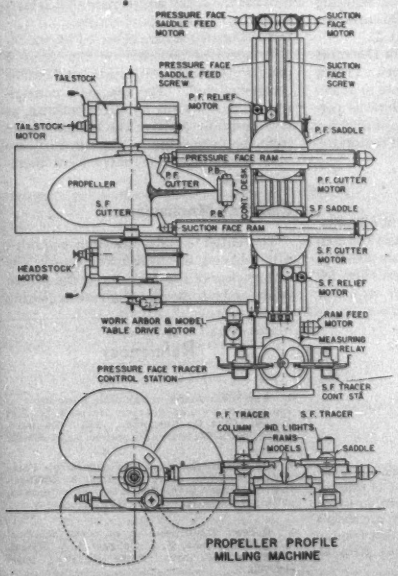

Figure 1 (left). Side elevation and plan view of propeller milling machine giving names of various parts as used in test

Figure 2 (below). General view of machine as installed

The control cubicle is at the left. The operator is stationed on the pit balcony. The control desk is also located here

buttons at a high or low fixed speed to facilitate setting up the machine.

Work-Arbor and Saddle-Feed Control

There is, naturally, a maximum limit to the speed at which the position regulators can follow and maintain the required accuracy of positioning. A speed of 50 inches per minute was set on this machine as the maximum usable feed speed for the cutter saddles. This corresponds to 500 rpm of the saddle-feed motors and is the maximum speed at which the position-regulating system must follow accurately.

During the return stroke when the cutters are in the relieved position, high accuracy is not necessary and, consequently, the saddle-feed motors can operate at their maximum speed of 1,000 rpm at this time. To insure that these limits will not be exceeded, a speed-regulating system is provided for the work-arbor motor. Two voltage relays are connected so as to be responsive to the voltage generated by the saddle-feed generators, and these relays are, therefore, responsive to the saddle-feed motor speed. These relays are set with a small differential in pickup voltage, and their contacts are arranged to control the motor-operated rheostat.

When the pickup voltage of the first relay is reached, the motor-operated rheostat is stopped if it has not already accelerated the work-arbor motor to maximum speed. If the position regulator calls for a greater speed from the saddle-feed motors than that allowed for by the differential setting of the two relays, the second relay will pick up causing the rheostat to decrease the work-arbor speed. The dropout point of the second relay is naturally higher than that of the first; consequently it will drop out and stop the rheostat before the voltage drops low enough to drop out the first relay.

The pickup voltage of both of these relays may be set by means of a rheostat that is located on the operator's control desk. This rheostat is used to set the speed of operation of the feeds.

The amount of metal to be removed may be much greater in some places than in others, and, therefore, the depth of cut may vary considerably. A cutter load-regulating arrangement is therefore provided. This consists of two additional relays similar to those already described but connected so as to be responsive to cutter motor current. The contacts of these relays control the work-arbor motor rheostat in the same manner as the voltage relays previously described. These relays also are provided with calibrating rheostats mounted on the control desk. Through the action of these relays, the work-arbor motor speed is regulated in accordance with the cutter load, slowing down when deep cuts or hard spots are encountered and speeding up again when the cutter load returns to normal.

Figure 3. View from control desk showing a propeller being machined

This shows the two cutters in cutting position

The saddle speed-limiting regulators and the cutter load regulators provide safety features which protect the machine and cutters automatically, thus relieving the operator from this responsibility while the machining operation is going on.

Push-Button Control for Setting Up

The contour of a ship propeller blade is a very irregular surface. There are few reference points available to use as datum points when setting up the machine. In setting up, the operator must position the rough propeller with respect to the model so that there will be enough stock at all points on each blade. This involves a rather tedious setting-up operation during which the various parts of the machine must be moved individually and, in some cases, several motions simultaneously and in synchronism.

Momentary-contact push buttons in portable push-button stations are provided for this purpose. These push buttons give an inching or jogging operation in which the motor rotates only so long as the push button is held depressed, and the motor is stopped quickly by dynamic or regenerative braking when the button is released.

Two fixed speeds are provided for the jogging operation. A fast speed is used to move the machine cutting elements rapidly into approximate position and a very slow speed for accurately positioning these members.

The jogging push buttons are contained in portable push-button stations provided with handles for easy portability, and long flexible cables enable the operator to carry these stations about so that he can take them to any necessary location while setting up the machine. Brackets are provided on the operator's desk which hold these portable push-button stations in an accessible position when they are not in use.

Automatic Operation

After the setting-up operation is completed, the electric circuits are arranged for automatic operation by means of selector switches on the various control stations. This prevents movement of any part by use of the jog buttons and makes the machine ready for full automatic operation.

The position regulators must be in operation and properly adjusted, the cutter motors must be running, and the relieving mechanism control must be set for automatic operation before the automatic cycle may be started. The automatic cycle always is started in the return direction. Depressing the "Auto-Return" push button starts the work-arbor motor and the motor-operated rheostat. The rheostat accelerates the motor until it reaches its maximum speed or until one of the tracer-controlled saddle-feed motors reaches its selected maximum speed, and the speed regulators take control. The work-arbor motor then continues to operate under control of the speed regulators, and the saddles operate under control of the position regulators which follow the model.

As the cutters approach the edge of the blade, the dogs on the model table operate the return-limit switch which starts the motor-operated rheostat in the direction to decrease the speed of the work-arbor motor. When the rheostat reaches its minimum speed position, the work-arbor motor is stopped. The relief-drive motors then move the cutter saddles into cutting position, and the work-arbor motor is started in the opposite direction. This motor again is accelerated by the motor-operated rheostat. There is a separate saddle-speed-limit control rheostat on the operator's desk so that the maximum speed of the saddle may be set for different speeds in each direction. This permits the operator to set the cutting speed for the best cutting condition while the return stroke may be made at a much faster rate. The motor-operated rheostat therefore stops when the saddle speed reaches the maximum determined by the setting of the saddle-speed-limit control rheostat for the cutting direction. During the remainder of the cutting stroke, the work-arbor motor speed is under control of both the speed-limit control and the cutter load-limit control. The cutter saddles are controlled by the position regulators.

When the cutters approach the other edge of the blade, the dogs on the model table operate the cut-limit switch, which starts deceleration of the work-arbor

motor through the action of the motor-operated rheostat, and again this motor stops when the rheostat reaches the minimum speed position. The relief-drive motors then move the saddle so that the cutters are clear of the work, and the work-arbor motor again is started in the return direction. At this same time, the ram-feed motor is started, and it operates for a definite number of revolutions as determined by the measuring relay; thus the rams are moved ahead a definite amount and the cutters will follow in a new path across the blade during the next cut stroke.

The machine will continue to follow this automatic cycle without further attention from the operator except the occasional adjustment of the model-table dogs which adjust the length of stroke to conform approximately to the outline of the blade.

The automatic cycle may be stopped at any time by depressing the "Stop" push button. This will cause relieving mechanisms to move the cutters clear of the work and the work-arbor motor to be decelerated just as is done at the end of the stroke. The work-arbor motor will stop when the motor-operated rheostat reaches the minimum-speed position and will not start again until a "Start" push button is depressed. The cutter motors will continue to run, and the position regulators will remain in operation.

An "Emergency-Stop" push button is provided which is intended for use only in an emergency such as might be caused by the breaking of a cutter or the like. When this button is depressed, the relieving mechanisms move the cutters away from the work, and the work-arbor motor and both saddle-feed motors are stopped quickly by regenerative braking. The position regulators are thrown out of operation. It is then necessary to synchronize the tracers with the cutters again and pick up the cut by adjustment.

Protective Devices

In addition to the protective features previously described, overtravel-limit switches are provided to protect against inadvertent movement of any part of the machine beyond its normal limit of travel.

If the tracer probes strike an obstruction, or if they fall off the model because the stroke-limit switches are not set correctly, limit switches that are built into the tracer head are operated. The operation of any of these limit switches has the same effect as depressing the "Emergency-Stop" push button.

There is a number of setup clutches on the machine which provide for different mechanical arrangements for various operations. To insure that these are set in their proper relative positions, various interlocking limit switches are arranged to be operated by these levers. These limit switches are connected into the control circuits in such a manner that the proper mechanical setup must be made before the machine can be operated.

Conclusion

The electric equipment applied on this machine provides reliable means, by the use of proved apparatus, for performing all of the functions required on a machine of this type. Several new problems of regulation, interlocking, and sequence control were encountered in the design of this equipment. Standard equipment was employed throughout with minor modifications to make it better suited for its particular use.

The successful completion of a machine tool of this type requires not only a consideration of the structural design of the machine parts to insure rigidity and accuracy, but also a co-ordination of design between the electrical engineer and the machine designer in arriving at the best solution for the kinematics of the machine. The proper operation of the mechanisms involved depend so much upon co-operative action between the electrical and mechanical devices, that the design of both must be considered simultaneously. It would have been very difficult to select and design electric equipment for this machine after the mechanical design had been completed. We believe that the outstanding machines of the future will be the co-operative efforts of electric-application engineers and the machine designers.

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Transient Response of Controlled Rectifier Circuits

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Synopsis: Transients in circuits supplied by controlled rectifiers using gas- or mercury-vapor-filled electron tubes are found analytically by an extended superposition method. Loads containing resistance, inductance, and a counter electromotive force are studied, and results are obtained for both rectification and inversion. Examples are based on the half-wave biphase rectifier, while the appendix contains an analysis of a p-phase rectifier. The assumptions include constant-circuit parameters, a fixed firing angle during transients, continuous load current, and no-leakage reactance in the supply transformer.

DESPITE the increasing use of rectifiers in industry, most of the analyses and reports in technical literature cover only the steady-state aspects of their operation. Little has been written about their performance with suddenly applied loads, with abrupt changes in operating conditions, or even with relatively common switching procedures.

As the field of their application has been widened and as more exact characteristics have been specified for them in these applications, the need for complete knowledge of their behavior has increased also. For instance, the rate at which the field in an eddy-current clutch can be strengthened affects the performance of a synchronous motor driving a wind-tunnel propeller through that clutch. Similarly, the transient characteristic of a motor or exciter field supplied from a rectifier is important when the field must be de-energized in an emergency. And much of the action during the reversing of a thyratron-controlled motor by inversion depends on the transient performance of the motor and the rectifier.

This paper has two main purposes. The first is to extend the existing published theory beyond steady-state analyses. The second is to call attention to an analytical method which is valuable as much for its simplicity as for its generality.

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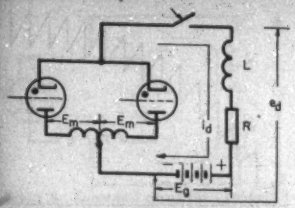


Figure 1. The equivalent circuit of a biphase half-wave controlled rectifier supplying a load containing resistance, inductance, and a counter electromotive force

Both rectification and inversion will be discussed.

Some simplifications are necessary, of course, to permit any analysis at all. The complete problem of finding responses in automatic control and regulating systems employing rectifiers is complicated immediately by the continuously changing firing angle of the rectifier tubes. To make a beginning, a constant firing angle is assumed throughout this paper. Most of the time this involves only a reasonable approximation, and part of the time it is an exact statement.

In addition, the load current is assumed to be continuous. Discontinuous conduction, in which the current pulses succeeding the first one are identical and in which no transient response lasts beyond each pulse, has already been discussed.[1]

To keep the analysis specific, only rectifiers using grid-controlled gas- or mercury-vapor-filled electron tubes will be mentioned. For simplicity, the half-wave biphase rectifier is studied exclusively in the main portion of this paper. Appendix II contains the general analysis of a p-phase rectifier.

Method of Analysis

If the switch in the circuit of Figure 1 is closed after the instantaneous voltage across the transformer winding passes through zero and before the firing point of the first tube is reached, the total voltage across the load, e_d, will appear as in Figure 2. The transient-current response to this voltage could be found by using ordinary differential equations, with successive boundary conditions to be evaluated tediously, or else by a Fourier series method, where the current responses to the d-c component and the fundamental and harmonic a-c components are determined separately.

Operational calculus, with either the Heaviside or Laplacian transform method, has at least two disadvantages. Most engineers have not had an opportunity to become proficient in its use, and frequently the problem of determining the proper operational forms is almost as difficult as the problem they are to solve.

Instead, the method suggested here is

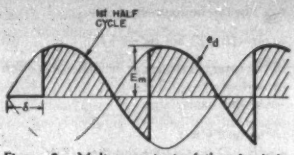


Figure 2. Voltage output of the circuit in Figure 1

based on the superposition theorem and an extension of the Duhamel integral.[2,3] It states merely that the total current in a linear circuit can be found at any time by superposing all the currents produced by separate voltage sources in the circuit, regardless of whether transient or steady-state responses are considered and despite the fact that each of the component currents may have started at a different time.

Figure 3 shows how a typical rectifier circuit, supplying a load containing resistance, inductance, and a counter electromotive force (pictured as a battery), can be studied as the sum of two circuits. The circuit in Figure 3B yields the current i_1, which is the component produced by the rectifier output voltage shown in Figure 2. In Figure 3C, only the current i_2 produced by the counter electromotive force is considered. Together, i_1 and i_2 comprise the total current response in the complete circuit.

Since the exponential rise of i_2 in Figure 3C is a relatively familiar phenomenon, finding i_1 as the result of the serrated rectifier output voltage presents the major difficulty. The first step, illustrated in Figure 4, is to decompose this voltage into continuous sine waves of the same frequency which start at regular intervals. Each voltage, moreover, is introduced at the same angle on its sinusoidal wave shape.

The first sine wave has the same peak value as the rectifier output voltage, and the sine waves thereafter have peak values twice as large and start at half-cycle intervals. When these waves are superposed, the resulting voltage wave is the original rectifier output voltage for which the response is desired.

If the beginning of the nth voltage wave is chosen as the zero axis of time, this wave can be expressed as

$$e_n = 2E_m \sin(\omega t + \delta) \tag{1}$$

in the interval $0 < \omega t < \pi$. Since each of the component waves begins π radians before the following one, the expressions for all of the components during this same interval will be

$$\left.\begin{aligned} e_{n-1} &= 2E_m \sin(\omega t + \delta + \pi) \\ e_{n-2} &= 2E_m \sin(\omega t + \delta + 2\pi) \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ e_3 &= 2E_m \sin[\omega t + \delta + (n-3)\pi] \\ e_2 &= 2E_m \sin[\omega t + \delta + (n-2)\pi] \\ e_1 &= E_m \sin[\omega t + \delta + (n-1)\pi] \end{aligned}\right\} \tag{2}$$

The current response to each of these components is simply the transient resulting when it is switched at the specified time into a circuit containing resistance and inductance. This response has the general form:[4]

$$i = (E/Z)\sin(\theta - \delta)\epsilon^{-t/T} + (E/Z)\sin(\omega t - \theta + \delta) \tag{3}$$

for an applied voltage of

$$e = E\sin(\omega t + \delta) \tag{4}$$

If E in equation 3 is replaced by $2E_m$, the general current expression becomes the exact response to the nth component wave. For the exact response to any of the component waves, it is necessary only to notice that, during the interval $0 < \omega t < \pi$, the existing component current produced by a voltage wave which started r half cycles earlier is identical with the current which will exist r half cycles later as the result of the nth component voltage.

If we let t_1 be the time for a half cycle, the current response to any of the component voltages can be found by substituting $(t + rt_1)$ for t in the expression for the current response to the voltage wave which precedes it by r half cycles. The currents in the interval $0 < \omega t < \pi$ thus appear as follows:

$$\left.\begin{aligned} i_n &= (2E_m/Z)\sin(\theta - \delta)\epsilon^{-t/T} + (2E_m/Z)\sin(\omega t - \theta + \delta) \\ i_{n-1} &= (2E_m/Z)\sin(\theta - \delta)\epsilon^{-(t+t_1)/T} + (2E_m/Z)\sin(\omega t - \theta + \delta + \pi) \\ i_{n-2} &= (2E_m/Z)\sin(\theta - \delta)\epsilon^{-(t+2t_1)/T} + (2E_m/Z)\sin(\omega t - \theta + \delta + 2\pi) \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ i_3 &= (2E_m/Z)\sin(\theta - \delta)\epsilon^{-[t+(n-3)t_1]/T} + (2E_m/Z)\sin[\omega t - \theta + \delta + (n-3)\pi] \\ i_2 &= (2E_m/Z)\sin(\theta - \delta)\epsilon^{-[t+(n-2)t_1]/T} + (2E_m/Z)\sin[\omega t - \theta + \delta + (n-2)\pi] \\ i_1 &= (E_m/Z)\sin(\theta - \delta)\epsilon^{-[t+(n-1)t_1]/T} + (E_m/Z)\sin[\omega t - \theta + \delta + (n-1)\pi] \end{aligned}\right\} \tag{5}$$

A. Original circuit, with the rectifier replaced by a source supplying the proper voltage

B. Circuit responding only to the rectifier voltage

C. Circuit responding only to the counter electromotive force

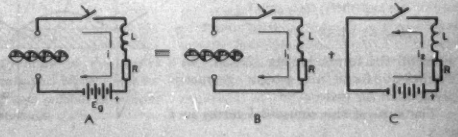


Figure 3. Equivalent representation of the circuit in Figure 1

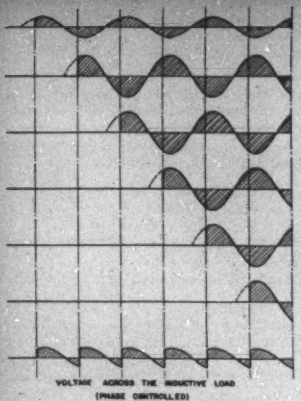


Figure 4. Decomposition of the output voltage of a biphase half-wave controlled rectifier into sinusoidal components

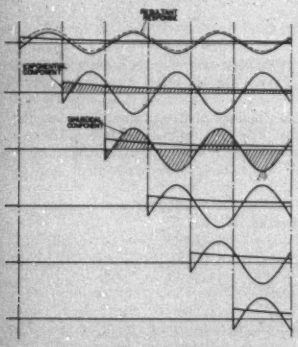


Figure 5. Current responses to the sinusoidal voltage components of Figure 4

The total current response, i_t, during the interval concerned is

$$i_t = i_1 + i_2 + i_3 \ldots i_{n-2} + i_{n-1} + i_n \qquad (6)$$

Since each component current in equation 5 consists of an exponential and a sinusoidal term, i_t is composed of an n-term group of exponentials and an n-term group of sinusoids.

By adding and subtracting $(E_m/Z) \times \sin(\theta-\delta)\epsilon^{-[t+(n-1)t_1]/T}$, the sum of the exponential terms in i_t can be rewritten as

$$i_{t(\exp)} = (2E_m/Z) \sin(\theta-\delta)\epsilon^{-t/T} \times [(1-\epsilon^{-nt_1/T})/(1-\epsilon^{-t_1/T})] - (E_m/Z) \sin(\theta-\delta)\epsilon^{-[t+(n-1)t_1]/T} \qquad (7)$$

since all the terms having $(2E_m/Z)$ as a coefficient form an n-term geometric series with the ratio $\epsilon^{-t_1/T}$.

The sum of the sinusoidal terms in i_t can always be expressed as

$$i_{t(\sin)} = (E_m/Z) \sin(\omega t - \theta + \delta) \qquad (8)$$

in the interval $0 < \omega t < \pi$, whether n is even or odd.

On this basis,

$$i_t = i_{t(\exp)} + i_{t(\sin)} = (E_m/Z) \sin(\omega t - \theta + \delta) + (2E_m/Z) \times \sin(\theta-\delta)\epsilon^{-t/T}[(1-\epsilon^{-nt_1/T})/(1-\epsilon^{-t_1/T})] - (E_m/Z) \sin(\theta-\delta)\epsilon^{-[t+(n-1)t_1]/T} \qquad (9)$$

Equation 9 is valid in the interval $0 \leqq \omega t \leqq \pi$ and gives the exact load current in the circuit of Figure 3B for the nth half cycle after the closing of the switch. The complete transient response can be found by letting n assume all the integral values from one to infinity, or to a number that brings the exponential terms as closely as desired to their limiting values.

A "physical picture" of this transient response can be obtained by considering the voltage components in Figure 4 as actual voltages which are switched into the load circuit at regular intervals. With linear circuit elements, each transient caused by the inclusion of another voltage source in the circuit behaves exactly as though it were the only transient present, and the total response at any instant is simply the sum of all the previously started transients. A convenient mathematical relation between these transients then makes it possible to express their sum in three terms.

Assumptions

The analysis presented in this paper is based on the following assumptions:

1. The load circuit contains only resistance, inductance, and possibly a counter electromotive force in series.
2. The resistance and inductance are constant.
3. If it is present, the counter electromotive force remains constant during the interval analyzed.
4. Leakage reactance in the rectifier supply transformer is negligible.
5. The arc drop of a rectifier tube is constant.
6. Ionization and deionization times in the rectifier tubes are negligible.
7. The angle of retard, δ, remains fixed during a transient.
8. Load current is continuous.

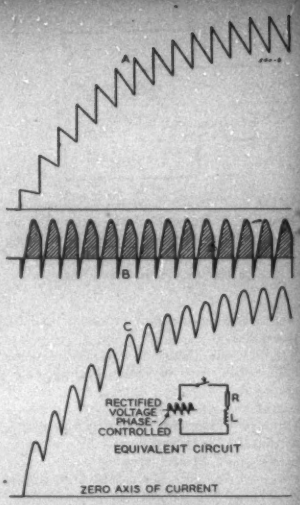


Figure 6. Current build-up in an inductive circuit supplied by a biphase half-wave controlled rectifier

A—Sum of the exponential components of the successive current responses
B—Sum of the sinusoidal components of the successive current responses
C—Total current response

9. The rectifying elements are grid-controlled gas- or mercury-vapor-filled electron tubes.

In general, these are standard assumptions, and the errors introduced are small compared to the main response.

Only resistance and inductance are considered in the load circuit, since shunt capacitance is ordinarily insignificant at power frequencies in industrial loads. When the counter electromotive force is generated in the armature of a d-c motor, assuming it to be constant requires that the speed of the motor remain unchanged during the transient period. It is usually an accurate assumption, depending only on the relative magnitudes of the electrical time constant, L/R, of the motor's armature circuit and the mechanical time constant, J/D (moment of inertia divided by the damping torque), of the shaft load. In a fully loaded one-horsepower 230-volt

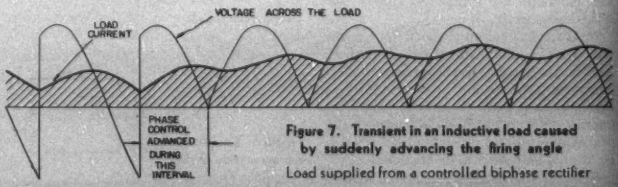


Figure 7. Transient in an inductive load caused by suddenly advancing the firing angle

Load supplied from a controlled biphase rectifier

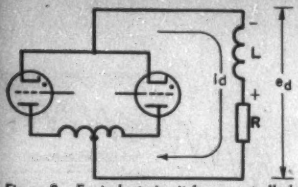


Figure 8. Equivalent circuit for a controlled biphase half-wave rectifier momentarily operating as an inverter from the energy stored in its inductive load

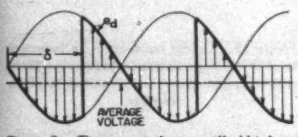


Figure 9. The output of a controlled biphase rectifier operating as an inverter

1,150-rpm d-c shunt motor, for instance, L/R may be in the order of 0.01 second whereas J/D, even assuming that the shaft load consists entirely of friction with no inertia, may be in the order of 0.4 second. With load inertia considered, J/D may easily exceed 1.0 second. If a series inductance is intentionally added for filtering purposes, however, this assumption must be studied carefully.

Rectification With no Counter Electromotive Force Present

If the arc drop of the rectifier tubes is neglected, transient currents in such loads as motor and clutch fields can be found from the circuit in Figure 3B by using equation 9. The transient-current responses to the sinusoidal voltage components of Figure 4, mentioned only briefly in the previous analysis, are illustrated in detail in Figure 5. Each one contains the sinusoidal and exponential currents which can be added, as in Figure 6, to obtain the total current response beginning with the closing of the switch.

Figure 6A shows the build-up of the exponential component expressed in equation 7, and Figure 6B, the sinusoidal component of equation 8.

The steady-state current can be obtained from equation 9 by letting n approach infinity.

$$i_{t-ss} = (E_m/Z)\sin(\omega t-\theta+\delta)+(2E_m/Z)\times \sin(\theta-\delta)[\epsilon^{-t/T}/(1-\epsilon^{-t_1/T})] \quad (10)$$

If $T \gg t_1$, as it may be if the load is heavily inductive, the first term in equation 10 will be very nearly equal to the ripple component of the load current, and the second term will closely approximate the d-c component.

Finally, if the load inductance, L is assumed to increase without limit, the ripple component of load current approaches zero and equation 10 becomes

$$i_{t-ss} = (2/\pi)(E_m/R)\cos\delta \quad (10a)$$

which is the well-established expression for the load current in a biphase half-wave rectifier supplying an infinitely inductive load.

This method of analysis is not limited to starting transients but applies equally well when the firing angle of the tubes is suddenly advanced as in Figure 7. Here the rectifier output voltage which formerly produced a certain load current is abruptly and completely replaced by a new output voltage. As far as the previous load current is concerned, the voltage causing it becomes zero, and it decays exponentially from the value i_0 that it had at the instant the new firing angle became effective. The component of the load current from the new output voltage begins, of course, from zero just as though there were no other component present; and the complete expression for the transient in Figure 7 is

$$i_t = i_0\epsilon^{-[t+(n-1)t_1]/T}+(E_m/Z)\times \sin(\omega t-\theta+\delta)+(2E_m/Z)\sin(\theta-\delta)\epsilon^{-t/T}\times [(1-\epsilon^{-nt_1/T})/(1-\epsilon^{-t_1/T})]-(E_m/Z)\times \sin(\theta-\delta)\epsilon^{-[t+(n-1)t_1]/T} \quad (9a)$$

in which δ is the new angle of retard.

Inversion With no Counter Electromotive Force Present

When a rectifier is supplying power to its load, it is operating as a rectifier in the normal sense; when it is absorbing power from the load, it is operating as an inverter. Current can pass through the rectifier tubes, however, in only one direction, and load current thus flows in the same direction for both rectification and inversion.

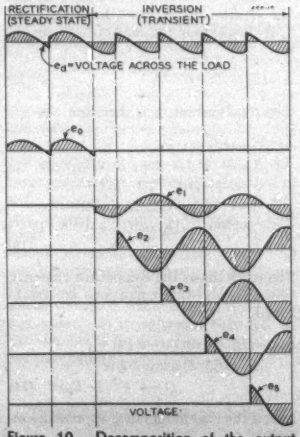


Figure 10. Decomposition of the output voltage wave of a controlled biphase rectifier suddenly transferring from rectifier to inverter operation

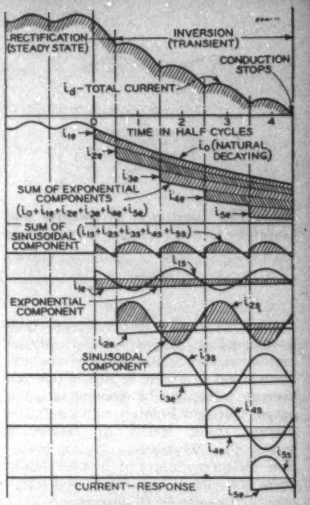


Figure 11. Total and component current responses in an inductive load supplied by a controlled biphase rectifier following an abrupt change from rectifier to inverter operation

To absorb power from some source in the load circuit, a rectifier therefore must have an output voltage which is either negative itself or, if positive, at least lower than the value necessary to keep the existing load current flowing through the load. In both cases, some energy source in the load circuit must supply power to keep the load current flowing.

A rectifier supplying an inductive load such as a field winding will operate momentarily as an inverter if the firing angle of the tubes is increased suddenly. While the current is dropping to its new level, the energy stored in the magnetic field will provide the power for inverter action. The equivalent circuit for the rectifier under these conditions is given in Figure 8, where the polarity markings by the inductance, L, show the induced voltage that maintains the flow of current.[6]

Since there is no external source of energy in the load circuit, continuous inversion is impossible, and the load current will drop either to a value that can be supplied by the rectifier with the new firing angle or to zero if the output voltage of the rectifier is negative. This characteristic provides rapid control of the current in inductive loads with no danger of excessive voltages. The stored energy is removed by delivering it through the rectifier back to the a-c supply lines.

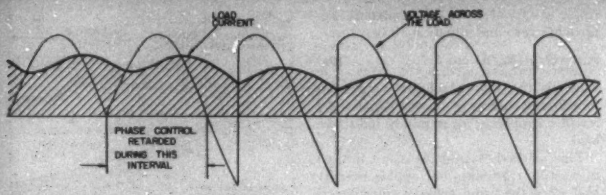


Figure 12. Transient in an inductive load caused by suddenly retarding the firing angle

Load supplied from a controlled biphase rectifier

Negative rectifier output voltages may seem startling. However, if the load current is somehow kept continuous, the output voltage in Figure 2, with a positive average value, can be changed into the output voltage of Figure 9, with a negative average value, merely by making δ greater than 90 degrees. During inversion, the energy source in the load circuit keeps the current continuous, and δ frequently does exceed 90 degrees.

Figure 10 illustrates this inverter action when firing is retarded. The top diagram shows how the output voltage changes as the firing angle is increased. In the decomposition of this output-voltage wave in the lower diagrams, e_0, the former output voltage as a rectifier, becomes zero at the instant inversion begins and is replaced by the succession of sinusoidal voltages, e_1, e_2, e_3, e_4, ...

If the transient response to each of these voltages is obtained, the total current during inversion can be expressed as the sum of an exponentially decaying component and the exponential and sinusoidal components of the current responses to each of the successive voltages. These component currents are shown in Figure 11. In the interval between the appearances of e_1 and e_2 in Figure 10, the current response is

$$i_1 = i_0\epsilon^{-t/T} - (E_m/Z)\sin(\omega t-\theta+\delta_1) - (E_m/Z)\sin(\theta-\delta_1)\epsilon^{-t/T} \quad (11a)$$

in which the time t is measured from the beginning of e_1, i_0 is the load current when $t=0$, and δ_1 is the previous angle of retard for operation as a rectifier.

In the succeeding half cycles, time is measured from the instant of appearance of the sinusoidal voltage component for that half cycle, and δ_2 is the new angle of retard for inverter operation. If the interval between the appearances of e_2 and e_3 in Figure 10 is considered as the second half cycle, the current in the nth half cycle will be

$$i_n = i_{0\epsilon}{}^{-[t+(\delta_2-\delta_1)/\omega+(n-2)t_1]/T} + (E_m/Z)\sin(\omega t-\theta+\delta_2) + (2E_m/Z)\times \sin(\theta-\delta_2)\epsilon^{-t/T}[(1-\epsilon^{-(n-1)t_1/T}) + (1-\epsilon^{-t_1/T})] - (E_m/Z)\sin(\theta-\delta_1)\times \epsilon^{-[t+(\delta_2-\delta_1)/\omega+(n-2)t_1]/T} \quad (11b)$$

Because the new angle of retard, δ_2, produces a negative rectifier output voltage, the top diagram in Figure 11 shows that conduction stops after several half cycles. (Actually, the current would become discontinuous with a very small average value rather than stopping altogether.) It illustrates how a motor or clutch field can be completely de-energized by sufficiently retarding the firing angle. If δ_2 is less than 90 degrees, however, the load current, instead of becoming zero, will merely drop to a new value as in Figure 12, and equations 11a and 11b still will apply.

Nothing has been said about the additional requirements for successful operation of the rectifier circuit during inversion since that subject is beyond the intent of this paper. It is well covered in technical literature and has been mentioned in at least one recent article in AIEE TRANSACTIONS.[6] The work in this paper is based on the tacit assumption that none of these requirements is violated.

Rectification With a Counter Electromotive Force Present

This is the original case illustrated in Figure 3A. The circuit in Figure 3B has already been analyzed; all that remains is a study of the circuit in Figure 3C and the addition of this result to equation 9.

By inspection, the current in Figure 3C is

$$i_2 = (E_b/R)(1-\epsilon^{-t/T}) \quad (12)$$

The total current, i_t, is therefore

$$i_t = i_{t(\exp)} + i_{t(\sin)} - i_2 = (E_m/Z)\sin(\omega t-\theta+\delta) + (2E_m/Z)\times \sin(\theta-\delta)\epsilon^{-t/T}[(1-\epsilon^{-nt_1/T}) + (1-\epsilon^{-t_1/T})] - (E_m/Z)\sin(\theta-\delta)\times \epsilon^{-[t+(n-1)t_1]/T} - (E_b/R)(1-\epsilon^{-[t+(n-1)t_1]/T}) \quad (13)$$

Figure 13 shows the component currents. When steady-state conditions are established,

$$i_{t-ss} = (E_m/Z)\sin(\omega t-\theta+\delta) + (2E_m/Z)\sin(\theta-\delta)[\epsilon^{-t/T} + (1-\epsilon^{-t_1/T})] - E_b/R \quad (14)$$

and, if the load inductance approaches infinity,

$$i_{t-ss} = (2/\pi)(E_m/R)\cos\delta - E_b/R \quad (15)$$

The arc drop of a rectifier tube may be considered as the counter electromotive force, E_b, if a more accurate solution is desired for the transient response in a load containing only resistance and inductance. E_b can also be an actual battery, the speed voltage in the armature of a d-c motor, or the sum of the tube drop and a counter-voltage in the load circuit.

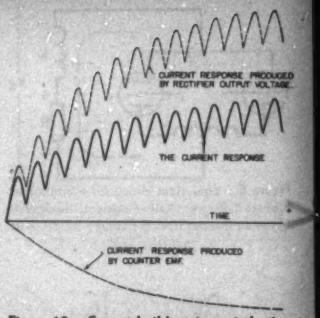

CURRENT RESPONSE PRODUCED BY RECTIFIER OUTPUT VOLTAGE
THE CURRENT RESPONSE
TIME
CURRENT RESPONSE PRODUCED BY COUNTER EMF

Figure 13. Current build-up in an inductive load containing a counter electromotive force and supplied from a controlled biphase rectifier

Equation 13 assumes that conduction begins when the first rectifier tube is fired after the switch in the load circuit is closed. Actually, this is true only when $E_m \times \sin\delta > E_b$, because conduction will not begin unless there is a positive-anode voltage across the incoming tube. If $E_m \sin\delta < E_b$, as illustrated in Figure 14, a slight correction is necessary in equation 13 to recognize that the first half cycle of current begins when $E_m \sin\omega t = E_b$.

Inversion With a Counter Electromotive Force Present

An equivalent circuit for inversion with a counter electromotive force in the load circuit depends on the polarity of that counter electromotive force. Figure 1 can be used if the counter electromotive force opposes the load current and the inverter action occurs as the angle of retard is increased to lower the value of the load current. The rectifier output voltage then will appear as in Figure 2, or possibly as in Figure 9 if the current is to be brought rapidly to zero.

From the equivalent circuit of Figure 1, the transient response can be determined immediately by adding the current rise caused by the counter electromotive force

Figure 14. Possible relations between transformer voltage and counter electromotive force at the instant of firing a tube in a biphase rectifier

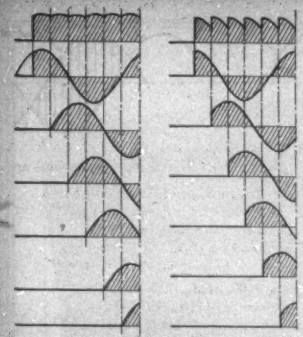


Figure 15 (left). Decomposition of the output voltage wave of a six-phase uncontrolled rectifier

Figure 16 (right). Decomposition of the output voltage wave of a six-phase controlled rectifier

to equations 11a and 11b. In the first half cycle,

$$i_1 = i_0\epsilon^{-t/T} - (E_m/Z)\sin(\omega t - \theta + \delta_1) - (E_m/Z)\sin(\theta - \delta_1)\epsilon^{-t/T} - (E_b/R)(1-\epsilon^{-t/T}) \quad (16a)$$

In the succeeding half cycles,

$$i_1 = [i_0 - (E_m/Z)\sin(\theta-\delta_1) + E_b/R]\epsilon^{-[t+(\beta_1-\delta_1)/\omega+(n-2)t_1]/T} + (E_m/Z)\sin(\omega t-\theta+\delta_2) - E_b/R + (2E_m/Z)\sin(\theta-\delta_2)\epsilon^{-t/T} \times [(1-\epsilon^{-(n-1)t_1/T})/(1-\epsilon^{-t_1/T})] \quad (16b)$$

When the counter electromotive force aids instead of opposes the flow of load current, it supplies energy to the circuit and continuous inversion is possible. If the transient is produced by retarding the firing angle in a circuit which is already operating as an inverter, the current response can be obtained directly from equations 16a and 6b by changing the sign of E_b wherever it appears. Then E_b becomes $(E_g - E_t)$ instead of $(E_g + E_t)$, since arc drop always opposes load current.

However, when the transient is caused by closing the main switch in the load circuit, the complete solution can be found from equations 13, 14, and 15, by reversing the sign of E_b and using $E_b = E_g - E_t$.

Polyphase Rectifier Circuits

To illustrate the generality of the method, Figures 15 and 16 show how the components of the voltage output of a six-phase rectifier are obtained. The transient current for controlled or uncontrolled operation can be determined as the sum of the responses to these voltage components.

Special Circuits and Abnormal Operation

Although the biphase rectifier output voltages studied so far are typical of the majority of such rectifiers, their uniform peak values and constant firing angles make them all special cases. The general case is shown in Figure 17 and could result from an unbalanced supply transformer winding, from dissimilar tube characteristics, or from both simultaneously as illustrated.

Despite the differences in peak transformer voltage and angle of retard, this output voltage can be resolved as before into sinusoidal components. All of these components, beginning with the second half cycle, have the same magnitude, $E_{m1} + E_{m2}$, although the moments of their entries depend on the firing angle, δ_1 or δ_2, in the corresponding half cycle of the complete output voltage. Appendix III contains the complete analysis of this general biphase case. For engineering work, the output voltages already used, while admittedly special cases, give sufficiently accurate results.

However, two special rectifier circuits deserve mention since transient responses in them can be obtained from the general biphase case. If one of the thyratrons in Figure 1 is replaced by a phanotron, which has no control grid, the result is sometimes called the "horse-and-ox" circuit, for reasons which become apparent on studying the output voltage in Figure 18. While the peak voltage is the same for all the half cycles, δ_1 definitely differs from δ_2. From the voltage components shown, the transient response is obtained as before.

The other special circuit, which has been termed the "free-wheeling" circuit, can be made by removing one half of the transformer winding in Figure 1 and replacing the corresponding thyratron by a phanotron. Its output voltage is given in Figure 19.

In addition to these variations of the biphase rectifier, certain abnormalities can occur also in polyphase circuits. For instance, if one anode in a six-phase rectifier supplying an exciter field were to become inoperative, it would be practical as well as desirable to know if the field current would remain continuous. This could be accomplished readily by decomposing the output voltage of Figure 20 and determining whether the current response during the interval of missing anode voltage is theoretically negative at any point. If it is, conduction will be discontinuous, for a reverse current cannot pass through a rectifier.

Appendix I. Nomenclature

R = resistance of load circuit, ohms
L = inductance of load circuit, henrys
ω = line frequency, radians per second

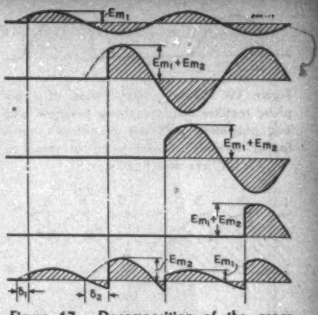


Figure 17. Decomposition of the generalized output voltage wave of a biphase rectifier, considering unequal anode voltages and firing angles

Z = load-circuit impedance at line frequency
$= (R^2 + \omega^2 L^2)^{1/2}$
T = time constant of load circuit, seconds
$= L/R$
θ = load-circuit power-factor angle at line frequency
$= \tan^{-1}\omega L/R$
E_m = peak value of the alternating voltage impressed on the load circuit
E_g = counter electromotive force in the load circuit, volts
E_t = rectifier-tube arc drop, volts
$E_b = E_g + E_t$ for rectification
$= E_g - E_t$ for inversion
p = number of rectifier phases
t_1 = nominal conduction time per phase (for continuous conduction), seconds
$= 2\pi/\omega p$
α = nominal conduction angle per phase (for continuous conduction), radians
$= \omega t_1 = 2\pi/p$
β = firing angle for uncontrolled rectification with continuous conduction, radians
$= (\pi - \alpha)/2 = \pi(p-2)/2p$
δ = angle by which firing is retarded beyond β, radians
γ = angle, in a p-phase rectifier, by which the firing of the first anode is retarded beyond δ due to closing of the switch to the load, radians
ϵ = general symbol for an applied voltage which is a function of time, usually accompanied by an identifying subscript but used without one in equation 4
E = peak value of the general sinusoidal voltage in equations 3 and 4
t = time, seconds

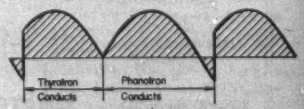


Figure 18. Output-voltage wave of a biphase rectifier employing one thyratron and one phanotron ("horse-and-ox" circuit)

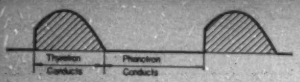


Figure 19. Output-voltage wave of a biphase rectifier employing one thyratron and one phanotron with the phanotron's transformer winding short-circuited or removed ("free-wheeling" circuit)

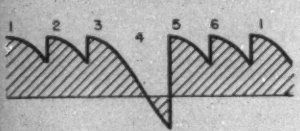


Figure 20. Output voltage of a controlled six-phase rectifier with one rectifying element inoperative

Appendix II. The *p*-Phase Rectifier

Figure 21 shows the rectifier output voltage of a p-phase rectifier. The immediate problem is to find the voltage that can be added to sin ωt to obtain sin $(\omega t-\alpha)$.

$$E_m \sin \omega t+f(t)=E_m \sin (\omega t-\alpha)$$
$$f(t)=-2E_m \sin (\alpha/2) \cos [\omega t-(\alpha/2)] \quad (17)$$

Thus $2E_m \sin (\alpha/2)$ is the peak value of the successive component voltages. These components can be summarized as follows, letting $t=0$ at the beginning of the nth component:

$$\left.\begin{aligned} e_n &= 2E_m \sin (\alpha/2) \sin (\omega t+\delta) \\ e_{n-1} &= 2E_m \sin (\alpha/2) \sin (\omega t+\delta+\alpha) \\ e_{n-2} &= 2E_m \sin (\alpha/2) \sin (\omega t+\delta+2\alpha) \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ e_2 &= 2E_m \sin(\alpha/2) \sin[\omega t+\delta+(n-2)\alpha] \\ e_1 &= E_m \sin [\omega t+\delta+(n-1)\alpha+\beta] \end{aligned}\right\} \quad (18)$$

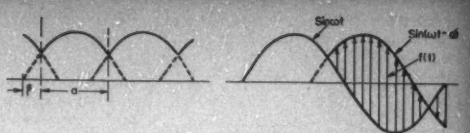
Equation 18 holds for $0<\omega t<\alpha$. The corresponding current responses are

$$\left.\begin{aligned} i_n &= 2(E_m/Z) \sin(\alpha/2) \sin(\omega t-\theta+\delta)+ \\ &\quad 2(E_m/Z) \sin (\alpha/2) \sin (\theta-\delta)\epsilon^{-t/T} \\ i_{n-1} &= 2(E_m/Z) \sin (\alpha/2) \sin (\omega t-\theta+ \\ &\quad \delta+\alpha)+2(E_m/Z) \sin (\alpha/2)\times \\ &\quad \sin (\theta-\delta)\epsilon^{-(t+t_1)/T} \\ i_{n-2} &= 2(E_m/Z) \sin(\alpha/2)\times \\ &\quad \sin (\omega t-\theta+\delta+2\alpha)+2(E_m/Z)\times \\ &\quad \sin (\alpha/2) \sin (\theta-\delta)\epsilon^{-(t+2t_1)/T} \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ i_2 &= 2(E_m/Z) \sin (\alpha/2) \sin [\omega t-\theta+\delta+ \\ &\quad (n-2)\alpha]+2(E_m/Z) \sin (\alpha/2)\times \\ &\quad \sin (\theta-\delta)\epsilon^{-[t+(n-2)t_1]/T} \\ i_1 &= (E_m/Z) \sin [\omega t-\theta+\delta \\ &\quad +(n-1)\alpha+\beta]+(E_m/Z) \\ &\quad \sin (\theta-\beta-\delta-\gamma)\epsilon^{-[t+(n-1)t_1-\gamma/\omega]/T} \end{aligned}\right\} \quad (19)$$

The total current response is

$$\left.\begin{aligned} i_t &= i_1+i_2+\cdots+i_{n-2}+i_{n-1}+i_n \\ &= (E_m/Z) \sin (\omega t-\theta+\delta+\beta)+ \\ &\quad 2(E_m/Z) \sin (\alpha/2)\times \\ &\quad \sin (\theta-\delta)\epsilon^{-t/T}[(1-\epsilon^{-(n-1)t_1/T})/ \\ &\quad (1-\epsilon^{-t_1/T})]+(E_m/Z)\times \\ &\quad \sin (\theta-\beta-\delta-\gamma)\epsilon^{-[t+(n-1)t_1-\gamma/\omega]/T} \end{aligned}\right\} \quad (20)$$

Figure 21. Output voltage of the general *p*-phase rectifier



for $0 \leqq t \leqq t_1$.

In steady state, equation 20 becomes

$$i_t=(E_m/Z) \sin (\omega t-\theta+\delta+\beta)+2(E_m/Z)\times \sin (\alpha/2) \sin (\theta-\delta)[\epsilon^{-t/T}/(1-\epsilon^{-t_1/T})] \quad (21)$$

If a counter electromotive force, E_b, is present, the steady-state solution is

$$i_t=(E_m/Z) \sin (\omega t-\theta+\delta+\beta)-E_b/R+ 2(E_m/Z) \sin (\alpha/2) \sin (\theta-\delta)\times [\epsilon^{-t/T}/(1-\epsilon^{-t_1/T})] \quad (22)$$

Appendix III. The General Biphase Rectifier

The voltage components shown in Figure 17 may be summarized in two ways. If n is odd,

$$\left.\begin{aligned} e_n &= (E_{m1}+E_{m2}) \sin (\omega t+\delta_1) \\ e_{n-1} &= (E_{m1}+E_{m2}) \sin (\omega t+\delta_1+\pi) \\ e_{n-2} &= (E_{m1}+E_{m2}) \sin (\omega t+\delta_1+2\pi) \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ e_3 &= (E_{m1}+E_{m2}) \sin [\omega t+\delta_1+(n-3)\pi] \\ e_2 &= (E_{m1}+E_{m2}) \sin [\omega t+\delta_1+(n-2)\pi] \\ e_1 &= E_{m1} \sin [\omega t+\delta_1+(n-1)\pi] \end{aligned}\right\} \quad (23a)$$

for $0<\omega t<(\pi+\delta_2-\delta_1)$.

If n is even,

$$\left.\begin{aligned} e_n &= (E_{m1}+E_{m2}) \sin (\omega t+\delta_2) \\ e_{n-1} &= (E_{m1}+E_{m2}) \sin (\omega t+\delta_2+\pi) \\ e_{n-2} &= (E_{m1}+E_{m2}) \sin (\omega t+\delta_2+2\pi) \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ e_3 &= (E_{m1}+E_{m2}) \sin [\omega t+\delta_2+(n-3)\pi] \\ e_2 &= (E_{m1}+E_{m2}) \sin [\omega t+\delta_2+(n-2)\pi] \\ e_1 &= E_{m1} \sin [\omega t+\delta_2+(n-1)\pi] \end{aligned}\right\} \quad (23b)$$

for $0<\omega t<(\pi+\delta_1-\delta_2)$.

Finding the current responses is complicated somewhat by the difference between δ_1 and δ_2. If n is odd, the current components are

$$\left.\begin{aligned} i_n &= [(E_{m1}+E_{m2})/Z] \sin (\omega t-\theta+\delta_1)+ \\ &\quad [(E_{m1}+E_{m2})/Z] \sin (\theta-\delta_1)\epsilon^{-t/T} \\ i_{n-1} &= [(E_{m1}+E_{m2})/Z] \sin (\omega t- \\ &\quad \delta_1+\pi)+[(E_{m1}+E_{m2})/Z]\times \\ &\quad \sin (\theta-\delta_2)\epsilon^{-[t+t_1+(\delta_1-\delta_2)/\omega]/T} \\ i_{n-2} &= [(E_{m1}+E_{m2})/Z]\times \\ &\quad \sin (\omega t-\theta+\delta_1+\pi)+[(E_{m1}+ \\ &\quad E_{m2})/Z] \sin (\theta-\delta_1)\epsilon^{-(t+2t_1)/T} \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ i_3 &= [(E_{m1}+E_{m2})/Z] \sin [\omega t-\theta+\delta_1+ \\ &\quad (n-3)\pi]+[(E_{m1}+E_{m2})/Z]\times \\ &\quad \sin (\theta-\delta_1)\epsilon^{-[t+(n-3)t_1]/T} \\ i_2 &= [(E_{m1}+E_{m2})/Z] \sin [\omega t-\theta+ \\ &\quad \delta_1+(n-2)\pi]+[(E_{m1}+E_{m2})/Z]\times \\ &\quad \sin (\theta-\delta_2)\epsilon^{-[t+(n-2)t_1+(\delta_1-\delta_2/\omega]/T} \\ i_1 &= (E_{m1}/Z) \sin [\omega t-\theta+\delta_1+ \\ &\quad (n-1)\pi]+(E_{m1}/Z)\times \\ &\quad \sin (\theta-\delta_1)\epsilon^{-[t+(n-1)t_1]/T} \end{aligned}\right\} \quad (24a)$$

for $0<\omega t<(\pi+\delta_2-\delta_1)$.

If n is even, the current components are

$$\left.\begin{aligned} i_n &= [(E_{m1}+E_{m2})/Z] \sin (\omega t-\theta+\delta_2)+ \\ &\quad [(E_{m1}+E_{m2})/Z] \sin (\theta-\delta_2)\epsilon^{-t/T} \\ i_{n-1} &= [(E_{m1}+E_{m2})/Z]\times \\ &\quad \sin (\omega t-\theta+\delta_2+\pi)+[(E_{m1}+E_{m2})/Z]\times \\ &\quad \sin (\theta-\delta_1)\epsilon^{-[t+t_1+(\delta_2-\delta_1)/\omega]/T} \\ i_{n-2} &= [(E_{m1}+E_{m2})/Z] \sin (\omega t-\theta+ \\ &\quad \delta_2+2\pi)+[(E_{m1}+E_{m2})/Z]\times \\ &\quad \sin (\theta-\delta_2)\epsilon^{-(t+2t_1)/T} \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ i_3 &= [(E_{m1}+E_{m2})/Z] \sin [\omega t-\theta+ \\ &\quad \delta_2+(n-3)\pi]+[(E_{m1}+E_{m2})/Z]\times \\ &\quad \sin (\theta-\delta_1)\epsilon^{-[t+(n-3)t_1+(\delta_2-\delta_1)/\omega]/T} \\ i_2 &= [(E_{m1}+E_{m2})/Z] \sin [\omega t-\theta+\delta_2+ \\ &\quad (n-2)\pi]+[(E_{m1}+E_{m2})/Z]\times \\ &\quad \sin (\theta-\delta_2)\epsilon^{-[t+(n-2)t_1]/T} \\ i_1 &= (E_{m1}/Z) \sin [\omega t-\theta+\delta_2+ \\ &\quad (n-1)\pi]+(E_{m1}/Z)\times \\ &\quad \sin (\theta-\delta_1)\epsilon^{-[t+(n-1)t_1+(\delta_2-\delta_1)/\omega]/T} \end{aligned}\right\} \quad (24b)$$

for $0<\omega t<(\pi+\delta_1-\delta_2)$.

The sum of the responses, when n is odd, is

$$i_t=(E_{m1}/Z) \sin (\omega t-\theta+\delta_1)+ [(E_{m1}+E_{m2})/Z] \sin (\theta-\delta_1)\epsilon^{-t/T}\times [(1-\epsilon^{-(n+1)t_1/T})/(1-\epsilon^{-2t_1/T})]-(E_{m2}/Z)\times \sin (\theta-\delta_1)\epsilon^{-[t+(n-1)t_1]/T}+[(E_{m1}+E_{m2})/Z][\sin (\theta-\delta_1)\epsilon^{-[t+(\delta_1-\delta_2)/\omega]/T}]\times [(1-\epsilon^{-(n+1)t_1/T})/(1-\epsilon^{-2t_1/T})] \quad (25a)$$

for $0 \leqq \omega t \leqq (\pi+\delta_2-\delta_1)$.

When n is even, the total current is

$$i_t=(E_{m2}/Z) \sin (\omega t-\theta+\delta_2)+ [(E_{m1}+E_{m2})/Z][\epsilon^{-t/T}]\times [(1-\epsilon^{-(n+2)t_1/T})/(1-\epsilon^{-2t_1/T})]\times [\sin(\theta-\delta_2)+\epsilon^{-(\delta_2-\delta_1)/\omega T} \sin (\theta-\delta_1)]- (E_{m2}/Z) \sin (\theta-\delta_1)\epsilon^{[t+(n-1)t_1+(\delta_2-\delta_1)/\omega]/T} \quad (25b)$$

for $0 \leqq \omega t \leqq (\pi+\delta_1-\delta_2)$.

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Installing KERITE
Submarine Power Cable
in Long Island Sound
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Westchester Lighting Co.

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Pioneers in Cable Engineering

Of course the Sheik is confused by Laytex-insulated wire. He's one of the countless number of men now seeing wire for the first time. In hot deserts and tropical jungles, in distant islands and freezing arctic lands—places where electricity has never before been harnessed, Laytex is demonstrating its marvelous properties as a wire. To many of the people in these lands, wire henceforth means Laytex.

But to us here at home, Laytex is more than the average wire. Under the strain of world-wide war, Laytex gives better performance than was ever expected of any wire under such gruelling conditions.

Military needs now take the entire output of Laytex Wires and Cables. But we hope the day is not far off when manufacture will be resumed for Residential and Commercial Building, Police and Fire Alarm Systems, Communications, Signalling, Power Control and other exacting services.

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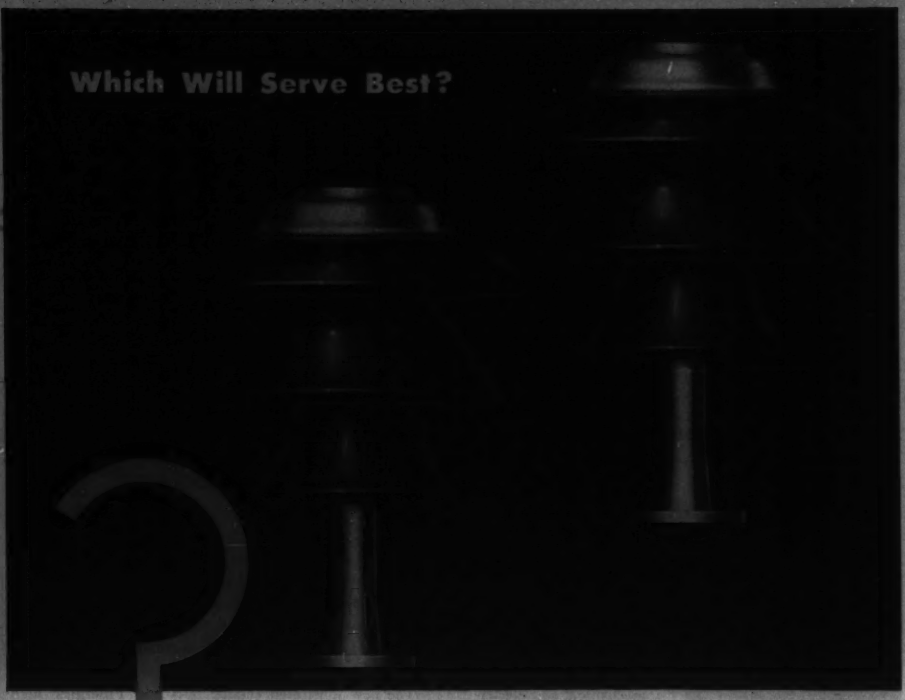

Take comparable station insulators of any two manufacturers and they look very much alike. Test them. They test alike both electrically and mechanically. Can we infer from this that they actually are just alike? Do the standards under which they are all built assure uniform results in service?

One thing that testing a new insulator out of stock cannot reveal is future performance, measured in terms of 30 years or more. The occurrence of heat, cold, climatic changes, and mechanical loads cannot be reproduced in the laboratory in proper sequence and combination, along with the element of time lapse. Simulated or accelerated tests are, at best, only indicators. If you want to know how your selected station insulator will be performing 30 years from now, it will take 30 years to find it out for sure; and an unfavorable answer may come to you long after it is too late to do anything about it. Frankly, the most important thing - reliability - is still bought on faith.

And what is the basis for this faith in O-B station insulators? Just this. Thousands of 30-year-old O-B units are still performing in vital spots today. These are the forefathers of a family now multiplied many hundred fold. Design refinements have been made which should improve this known performance.

Authentic service records that cover large numbers and long time, and that are open to the prospective buyer, are not claims but facts! They are proof of that quality of reliability that can't be covered in a set of specifications. When you buy O-B, you get everything that can be specified, plus that which cannot -- long, trouble-free service.

2596-H

Ohio Brass

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CANADIAN OHIO BRASS COMPANY, LIMITED,
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Designers and manufacturers of many types of electrical equipment—from tiny control devices to huge stators—are utilizing the extra mechanical and electrical advantages which only Fiberglas-base Insulation Materials afford. The use of this better material also assures users of such equipment, greater protection against time and dollar losses.

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Fiberglas is glass in fiber form—as such, it retains some of the characteristics commonly associated with glass and gains others which make it an unsurpassed insulating material, *when properly impregnated*. In textile form Fiberglas provides a thin, extremely strong, flexible, inorganic fabric base for impregnants and is available in such forms as: Magnet wire, Lead wire, Special wires and cables; Varnished cloth and tape; Mica-Combinations; Laminates; Saturated sleeving; Varnished tubing; Pressure-sensitive tapes and special products.

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HIGH VOLTAGE Ceramic Condensers

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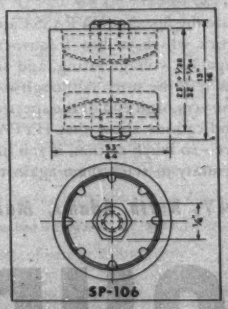
FOR HIGH FREQUENCY USE

These compact, high voltage condensers are designed to carry appreciable amounts of current at high voltage without danger of corona or excessive internal heat. The silvered ceramic construction provides choice of temperature coefficient, excellent stability and retrace characteristics. Two sizes are illustrated above.

Type SP-106 is rated at 5 KVA. Peak working voltages at sea level for types SP-106 and SP-172 are as follows:

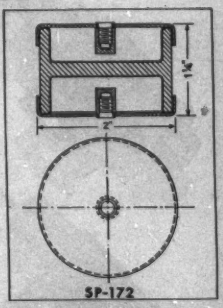


SP-106

Capacity	Temperature Coefficient	Peak Working Volts at Sea Level
20 MMF	NPO	10,000
30 MMF	NPO	6,500
39 MMF	NPO	5,000
51 MMF	N-750	10,000
75 MMF	N-750	7,500
100 MMF	N-750	5,500

SP-172

51 MMF	NPO	10,000
75 MMF	NPO	10,000
100 MMF	NPO	10,000
200 MMF	N-750	10,000
300 MMF	N-750	10,000
390 MMF	N-750	8,000



If you have applications for condensers of this style for either military or peacetime equipment, our engineers will be glad to discuss them with you.

Note: Test voltage, SP-106 and SP-172—60 cycle RMS equal to peak working voltage.

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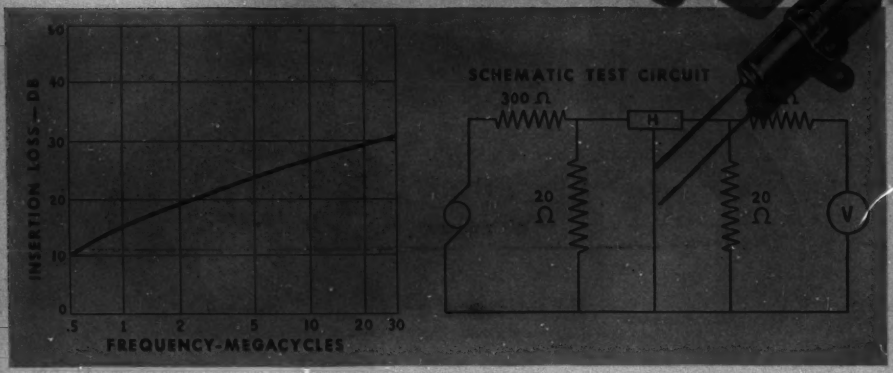
SPRAGUE HYPASS CAPACITORS



Curve showing insertion loss of a Sprague HYPASS Capacitor.

The Solution to "WHAT TO DO WITH ANTI-RESONANT FREQUENCIES?"

Conventional methods of getting rid of vibrator "hash" usually call for the use of a by-pass capacitor, shunted by a mica capacitor. This system, however, has at least one anti-resonant frequency. Of course the engineer juggles his constants so that this anti-resonant frequency comes where it causes the least trouble—BUT, in today's all-wave devices, there just isn't any such place!

The New Sprague Method is simply to utilize the Sprague HYPASS Capacitor. Technically, this is a 3-terminal network which, at low frequencies, "looks" like a capacitor in respect to its capacity, voltage rating, and size. At high frequencies—well, the above diagram tells the story. Although accurate measurements of their performance at the very high end of the spectrum are difficult to obtain as yet, qualitative indications show that HYPASS units do the job at 100 megacycles and more—so much so that, if you have a "hash" problem, we'd welcome an opportunity to stack them against it.

SPRAGUE ELECTRIC COMPANY, *North Adams, Mass.*
(Formerly Sprague Specialties Co.)

*T. M. REG. U. S. PAT. OFFICE

SPRAGUE

ARMY E NAVY

CAPACITORS — *KOOLOHM RESISTORS

For Post War Rural Applications

Two and one-half million farms now use electric power. Over three million others are considered to be prospective users of electric power. And with many rural electric power projects in prospect for the post-war period, the future of the farmer as a buyer of electrical equipment is assured. At the same time, a study of the trend toward farm mechanization and electrification during recent years indicates that much must be done to improve the transmission and distribution of power in rural areas.

New AmerTran Distribution Transformers for rural service are designed for unusual ruggedness and freedom from trouble. Such qualities are particularly required in rural electrification because of the greater distances involved, the comparative inaccessibility of installations and their exposed locations.

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LOOK FOR THESE ADVANTAGES IN THE NEW AMERTRAN DISTRIBUTION TRANSFORMERS

Lower Exciting Current
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Improved Tank Construction
Coordinated Insulation
Improved Regulation . . . New Terminal Facilities

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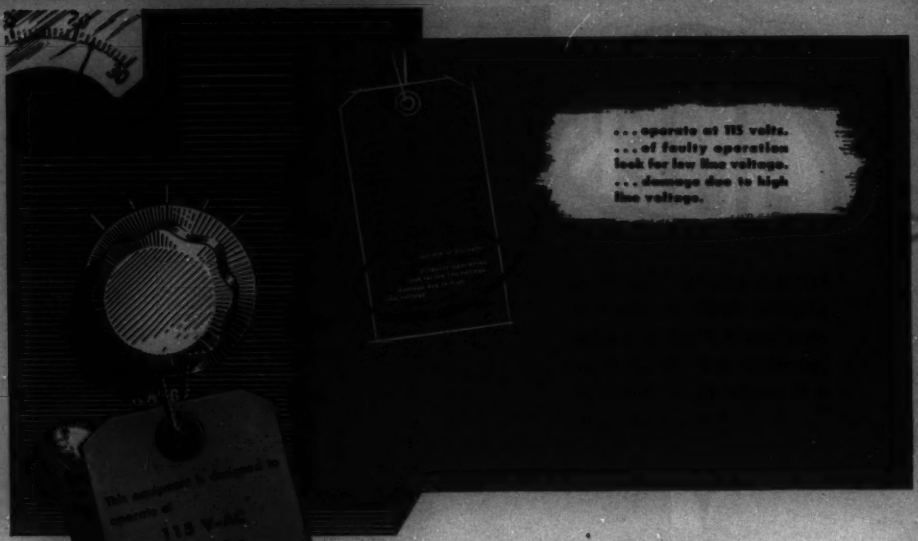

Warnings against unstable voltages are unnecessary on equipment protected with built-in CONSTANT VOLTAGE

Unstable voltage on commercial power lines is so prevalent that many manufacturers of electrical and electronic equipment have found it necessary to warn their customers of its existence and its possible effects on the operation and efficiency of the equipment.

There is an easy and inexpensive solution to this important problem —specify a SOLA CONSTANT VOLTAGE TRANSFORMER as a component part of your equipment. There are several types of SOLA CONSTANT VOLTAGE TRANSFORMERS specially designed for this purpose—small, compact units in capacities ranging from 10VA to several KVA. Other capacities and designs can be custom built to your specifications.

Once installed in your equipment they require no pampering or supervision. They are fully automatic, instantly correcting voltage fluctuations as great as ±15%. They are self-protecting against short circuit.

No sales manager will overlook the added salability of a product that features this guarantee of performance, low maintenance cost and satisfaction to the user.

SOLA engineers with wide experience in the application of the SOLA CONSTANT VOLTAGE principle are available for consultation on details of design specifications.

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IN A BUTTERFLY CIRCUIT

$$L = 2.12r\left(\ln\frac{36r}{t+w} - 2\right) \text{ centimeters}$$

If you haven't seen these plates before, you may think them the futuristic effort of a designer on the day after the night before. Actually they represent some of the steps in the development of an entirely new circuit for ultra-high-frequency use.

The problem of designing a compact ultra-high-frequency circuit with a large and continuously-adjustable range, and with no sliding contacts, is a difficult one.

Transmission lines, with none of these desirable features, have been used widely in the past. They offer numerous mechanical difficulties, very precise machine work being required to obtain acceptable accuracy. In addition, very often they are too large to be incorporated in many instruments.

The new circuits, developed by General Radio, are for obvious reasons called Butterfly Circuits. They have no sliding contacts, afford a tuning ratio of about 4 to 1, are very compact, can be designed for a satisfactory value of Q, and are mechanically comparatively simple.

The design of Butterfly Circuits is described in detail in the October 1944 issue of the G-R *Experimenter*. If you haven't seen a copy, we'd like to send you one.

WRITE FOR BULLETIN 917

GENERAL RADIO COMPANY Cambridge 39, Massachusetts
NEW YORK CHICAGO LOS ANGELES

In a wind tunnel an **AERONAUTICAL ENGINEER** uses a 40,000 horsepower electric motor to create a 400-mile-an-hour tornado for testing war planes.

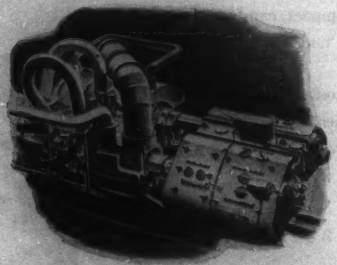
. . . the name on the MOTOR is Westinghouse.

In a factory a **WORKER** assembles delicate bomb-sight parts in air made dust-free by the Precipitron* electrostatic air cleaner.

. . . the name on the PRECIPITRON is Westinghouse.*

In a penicillin plant a **SCIENTIST** uses a Sterilamp* bactericidal tube to protect this life-saving drug from contamination by air-borne bacteria.

. . . the name on the STERILAMP is Westinghouse.*



On America's largest aircraft carriers the **NAVY** uses steam turbines which make our carriers the world's fastest.

. . . the name on the TURBINES is Westinghouse.

Westinghouse

PLANTS IN 25 CITIES OFFICES EVERYWHERE

TODAY — These are some of the ways in which Westinghouse products are serving in the war effort.

TOMORROW — Existing and new products of Westinghouse research and engineering will serve industry and the home.

Tune in: JOHN CHARLES THOMAS—Sunday 2:30 pm, EWT, NBC. TED MALONE—Mon. Tues. Wed. Evening, Blue Network

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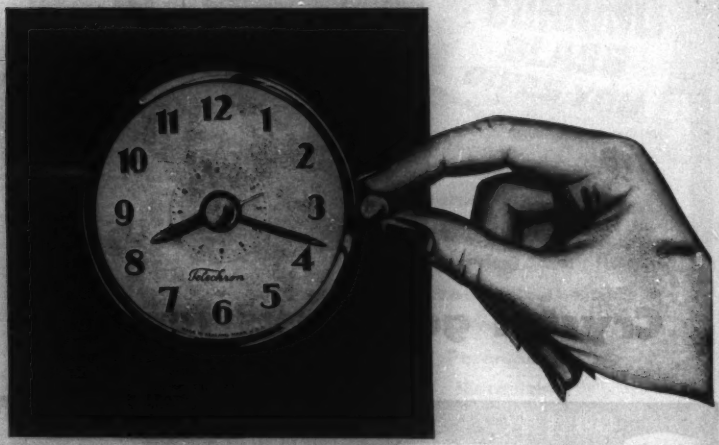
BUILD IT IN!



Telechron Electric Radio Switch Clock for quick-moving post-war receiver sales!

Telechron C40, electric radio switch clock, is a top-flight, A-1 sales booster for lower price receivers. The owner pre-sets the operating time—C40 turns on the station, *on the dot*, and also serves as an ideal alarm clock. Single control knob. A handsome time-saver that should be standard equipment on every radio designed for mass appeal. Low installation cost. Attractive pattern for panel mounting. Furnished in varying dial sizes, with dial and hand styles to meet your requirements. Famed Telechron accuracy, long life, dependability. Other styles and sizes for other radio requirements. Get the full, profitable facts now! Write or wire Automatic Control Division, Dept. F, Warren Telechron Co., Ashland, Mass.

COMPLETELY AUTOMATIC PRE-SELECTOR

Telechron Timer C32 offers complete automatic pre-selection of as many as 48 different 15-minute radio programs in sequence. Timer turns radio on for desired operating period, then turns it off. A flick of the finger sets the keys around the large and legible clock face. For panel mounting.

Telechron

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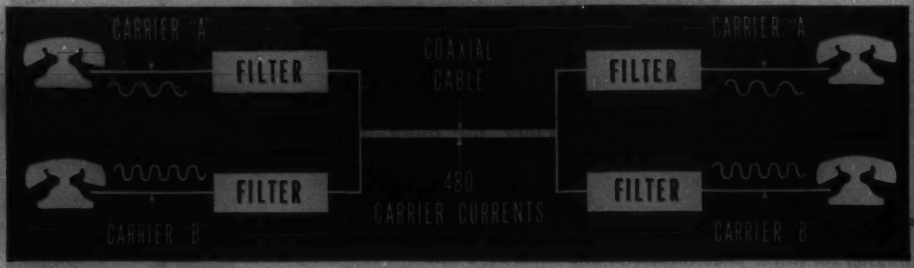
Crystal gateways for your voice



Four hundred and eighty telephone conversations over a coaxial cable was one of the last peacetime achievements of communication research in Bell Telephone Laboratories. In this multi-channel telephone system, each conversation is transported by its own high-frequency carrier current. At each end of the line are crystal gateways; each opens in response to its own particular "carrier" with the message it transports. In telephone terminology, these gateways are filters.

The ultra-selective characteristic of these filters is made possible by piezo-electric quartz plates, cut in a special manner from the mother crystal, and mounted in vacuum. Each set of plates is precisely adjusted so that the filter responds only to the frequency of its assigned channel, rejecting all others. In the coaxial terminal equipment, such crystal gates sort out messages for delivery to their four hundred and eighty individual destinations.

In recent years, Bell Telephone Laboratories research has provided the Armed Forces with many types of electrical equipment in which frequency is controlled by quartz crystals. Notable is the tank radio set which enables a tank crew to communicate over any one of 80 different transmission frequency channels by simply plugging in the appropriate crystal. The future holds rich possibilities for the use of quartz crystals in Bell System telephone service.

BELL TELEPHONE LABORATORIES

Exploring and inventing, devising and perfecting for our Armed Forces at war and for continued improvements and economies in telephone service.

WHAT WILL YOU NEED TO PRODUCE BETTER POST-WAR PRODUCTS?

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High dielectric strength—high resistivity—low power factor—wide range of dielectric constants—low losses at all frequencies.

Permanent hermetic seals against gas, oil and water readily made between glass and metal or glass and glass.

Commercial fabrication to the fine tolerances of precision metal working.

Corning's metallizing process produces metal areas of fixed and exact specification, permanently bonded to glass.

AS YOU plan post-war electronic products, give a thought to versatile glass. We really mean glasses, for Corning has, at its fingertips, 25,000 different glass formulae from which to select those especially suited to your electronic applications. Let us show what glass can do for you. We may already have a solution — or Corning Research can find the answer for you. Address Electronic Sales Dept., Bulb and Tubing Division. Corning Glass Works, Corning, New York.

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"WE USE EIMAC TUBES EXCLUSIVELY IN ALL OUR LARGER GROUND STATIONS"

Says Robert F. Six

PRESIDENT, CONTINENTAL AIR LINES

CONTINENTAL AIR LINES, INC.
MUNICIPAL AIR TERMINAL
Denver 7, Colorado

January 9, 1945

Chief Engineer
Eitel-McCullough, Inc.
870 San Mateo Avenue
San Bruno, California

Dear Sir:

An airline must have a communication system which is absolutely dependable. For that reason, we scrutinize with great care the records we keep on the performance of the various components used in our transmitting and receiving equipment.

Included among these records are those on Eimac transmitting tubes—used exclusively in all of the larger ground stations operated by Continental Air Lines. I am pleased to tell you that these records show that your transmitting tubes are averaging well over 20,000 hours of service in our stations.

Sincerely yours,

Robert F. Six
President

RFS/lad

ROBERT F. SIX
President
Continental Air Lines

Below... a pair of Eimac 450-T tubes in the panel of Continental ground station transmitter built by Wilcox.

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A NEW "MEMORY" RELAY

with simplified interlock

A new style interlock represents latch-in relay construction in its simplest, most dependable form. Design of this Struthers-Dunn 50XBX series simplifies make-before-break, or break-before-make contact combinations. Contacts do not interrupt coil circuit until the "throw" is completed and they are latched in new position. Built to aviation specifications.

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The extreme reliability with which this Struthers-Dunn Type 78CCA100 Vacuum Tube Keying Relay holds its adjustments is the direct result of a rigid and simplified design utilizing an absolute minimum of parts. Exceptionally sturdy—designed for aircraft. All parts readily accessible.

7 poles including one D.T. pole handling high-voltage r-f currents by means of a vacuum switch. High-voltage parts rounded to reduce corona.

SENSITIVE SNAP-ACTION

In a new, simplified design

Applications for the Struthers-Dunn Type 79XAX Sensitive Snap-Action Relay range from vacuum tube circuits, to overcurrent protection, pulsing circuits, and jobs where extremely close differential or extreme sensitivity are required. Contacts remain in position *with full pressure* up to the instant of transfer. Write for Bulletin No. 251.

SHOCKPROOF to 90 G's

Here's a relay that won't operate unintentionally as a result of shock or vibration—the Struthers-Dunn Type 17AXX designed to meet exacting B2A specifications. Small in size, light in weight, it meets and exceeds all specifications for such services.

WRITE—*for your copy of the big Struthers-Dunn Relay Catalog and Data Book . . .*

EXTRA HEAVY-DUTY CONTACTS

Struthers-Dunn Nutcracker Type 61HXX100 meets the call for relays for extreme services, particularly where severe overloads may cause trouble on units having a less generous heavy-duty contact safety factor. Typical applications include those such as aircraft landing light controls, or controlling a number of solenoids simultaneously. Readily adaptable to different specifications.

STRUTHERS-DUNN, INC., 1321 ARCH ST., PHILA. 7, PA.

STRUTHERS-DUNN

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DISTRICT ENGINEERING OFFICES: ATLANTA • BALTIMORE • BOSTON • BUFFALO • CHICAGO • CINCINNATI • CLEVELAND DALLAS • DENVER • DETROIT • HARTFORD • INDIANAPOLIS • LOS ANGELES • MINNEAPOLIS • MONTREAL NEW YORK • PITTSBURGH • ST. LOUIS • SAN FRANCISCO • SEATTLE • SYRACUSE • TORONTO • WASHINGTON

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Now Available!

G-E CAPACITORS

that conform to

AMERICAN WAR STANDARD

Fixed paper-dielectric G-E capacitors that conform to American War Standard proposed JAN C-25 (superseding C-75.16—1944) are now available with characteristics E and F, and with capacitance tolerance of 10 per cent (K), in the following case styles:

CP-50, -51, -52, -60, -62, -64, and -70.

The CP-70 units are available with B (solder lug) terminals, and with D and E (pillar insulator) terminals.

Removable mounting brackets of either the footed type or the screw-spade-lug type can be supplied for mounting the CP-70 units.

The service reliability of these G-E capacitors is backed by more than a quarter century's experience in the manufacture of capacitors of all types. For complete data, write for Bulletin GEA-4357.

Buy all the BONDS you can —and keep all you buy

Some of the fixed paper-dielectric G-E capacitors that conform to American War Standard

STANDARD RATINGS

CP-50, -51, AND -52 — **CHARACTERISTIC F**

Voltage	Range of Capacitance Values in Mu f		
	Single Section	Dual Section*	Triple Section*
600	.05 to 2.0	.05 to 1.0	.05 to .5
1000	.05 to 1.0	.05 to .5	.05 to .25

CP-60, -62, AND -64 — **CHARACTERISTICS E AND F**

Voltage	Range of Capacitance Values in Mu f	
	Single Section	*Dual Section
600	.05 to 1.0	.05 to .5
1000	.01 to .3	.01 to .25
1500	—	.01 to .05

CP-70 (SINGLE SECTION) — **CHARACTERISTICS E AND F**

Voltage	Range of Capacitance Values in Mu f		
	B Terminals	E Terminals	D Terminals
600	.25 to 10	.25 to 10	—
1000	.1 to 15	.1 to 15	—
1500	.1 to 15	.1 to 15	—
2000	—	.1 to 15	—
2500	—	.1 to 12	.1 to 6
3000	—	.1 to 6	.1 to 6
4000	—	.1 to 4	—
5000	—	.1 to 4	—
6000	—	.1 to 2	—
7500	—	1.0 to 2	.1 to .5
10000	—	.1 to 2	—
12500	—	.5 to 2	.1 to .25

*Capacitance per section of dual and triple section units. Dual and triple section units have capacitance tolerance of plus 20 per cent, minus 10 per cent (V).

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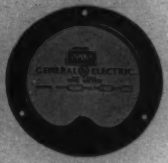
DIGEST

A LOT OF INSTRUMENT
in a little space

These thin, internal-pivot panel instruments have high torque, good damping, and a lightweight moving element that withstands vibration. They respond rapidly and accurately. They give you more instrument in less space, because the internal-pivot construction makes the entire element assembly 20 per cent thinner than outside-pivoted types. Ask for details of the Type DW voltmeter or ammeter—milli, micro, or radio frequency. Bulletin GEA-4064.

TO KEEP TABS ON TIME



For applications in which it is desired to keep track of the total operating time of electronic tubes or other electric devices, our Type KT time meters can provide an accurate record—in hours, tenths of hours, or minutes. Powered by precise, long-lived Telechron synchronous motors, these meters are available for panel or conduit mounting, and in portable form. For use on 60-, 50-, or 25-cycle circuits of 11 to 460 volts, to match the operating characteristics of various machines. Bulletin GEA-3299.

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via vu standard

To standardize measurement of sound, and make broadcast monitoring more effective, these vu volume-level indicators were developed to meet the rigid electric, dynamic, and mechanical specifications formulated by NBC, Columbia, and Bell Telephone Laboratory engineers. This G-E instrument employs the vu, a new standard of measurement. The zero reference is one milliwatt in a load of 600 ohms, and the vu unit is numerically equal to the number of decibels above or below this reference level. Ask for Bulletin GEA-3145A.

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. . . . . GEA-4064 (on small panel instruments)
. . . . . GEA-3299 (on time meters)
. . . . . GEA-3145A (on volume-level indicators)

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EVERY FRACTIONAL HORSEPOWER MOTOR HAS A BRUSH PROBLEM

HEADQUARTERS FOR MOLDED CARBONS, GRAPHITES, METALS, AND COMPOSITIONS

Brushes and Contacts (All carbon, graphite, metal, and composition types)
Rare Metal Contacts
Bearings Welding Carbons
Packing, Piston and Seal Rings
Continuously Adjustable Carbon Rheostats
Sintered Iron Components
Fixed and Variable Resistors, etc., etc.

. . . and here's why

A fractional horsepower motor brush for use on 110 V. requires an entirely different composition of ingredients than one to be used on a similar motor but, say, for 6 V. operation. Again, a brush that may do very well on one make or type of vacuum cleaner will be regarded as only mediocre on another—even though the points of electrical or mechanical difference are so small as to seem unimportant.

Almost without exception, small motors differ in their brush requirements. Even a slight difference in the "mix" of a brush may—and often does—make a whale of a difference in its life or performance. Emphasis on long life, or quiet operation, or minimum commutator wear, or various other factors should all be considered—*and in the light of the specific application!*

Backed with unparalleled experience in the production of more small motor brushes for more applications than any other manufacturer, Stackpole engineers are in an enviable position to help you in this all-important respect. Moreover, for 25 years, it has been their practice to have customers send their equipment to our laboratories. Thus, Stackpole brush recommendations are made NOT by guesswork, but on the sound basis of exhaustive tests on the actual equipment.

STACKPOLE CARBON COMPANY, St. Marys, Pa.

STACKPOLE

THE NATION'S LARGEST PRODUCER OF SMALL MOTOR BRUSHES

MOTOR MAINTENANCE—*Today's Important Factor*

NOW, more than ever before, it is extremely necessary that the electric motors, generators, etc., which play such a vital part in our production set-up, function smoothly and efficiently. This equipment cannot be easily replaced . . . preventive steps must be taken to prolong its life and guard against burnouts and failures.

One of the prime factors contributing to motor failure is worn insulation. Holes and cracks develop in the original insulation . . . acids, oils, moisture and carbonaceous particles slowly break down the varnish film on windings . . . yet, this condition is quickly and efficiently overcome by renewing this insulation with a coat of DOLPH'S ELECTRIC LACQUER at regular intervals.

ELECTRIC LACQUER, a black air drying varnish, can be applied by either brushing or spraying. Air drying in 30 minutes, this material provides a high degree of resistance to oil, water and the abrasive action of dust particles.

The application of **ELECTRIC LACQUER** will not interfere seriously with your production, for it is not necessary to shut down electrical equipment except during the application process.

Let **ELECTRIC LACQUER** aid you in your preventive maintenance work, as it has for many others throughout industry.

ELECTRIC LACQUER • (TRADE MARK REGISTERED)

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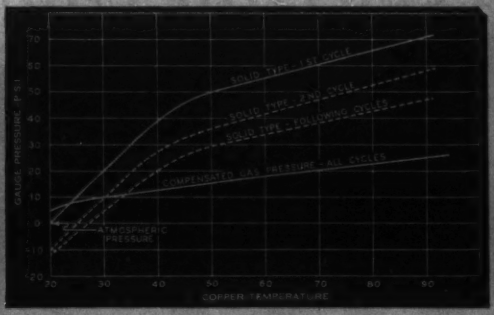
THE GAS CUSHION STABILIZES PRESSURES

WITHIN FIXED LIMITS IN THIS NEW PAPER INSULATED POWER CABLE



Solid Cable versus Type PC. A comparison of internal pressures under load.

TYPE PC PRESSURE COMPENSATED CABLE

USS STEEL — UNITED STATES STEEL

Other products of American Steel and Wire Company

- Amerclad Portable Cable
- Amerbestos Cable
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- Amarine Submarine Cable
- Reliance Weatherproof Wire
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to insure maximum heat-cycle life!

IMPROVED mechanical design, thorough impregnation, and "unique gas cushion" are the features in this new paper cable.

When the loads are applied and cable temperatures go through wide gyrations, manifold gas cushions absorb expanding oil and stabilize internal pressure within fixed and narrow limits. Uniform pressures exist along cable length regardless of contour. Thorough initial saturation and uniform pressure above atmospheric, preclude void formation with resulting ionization discharges and rapid deterioration of paper and insulating compounds. The latter are chosen for their stability and optimum viscosity characteristics rather than for "waxing" and "self-healing" properties.

Type PC Pressure Compensated Cable is an outstanding development in the long history of American Steel & Wire Company electrical wire and cable manufacture. It was designed to provide maximum reliability in transmission of power commensurate with reasonable first cost. Disadvantages of old types of cable have been eliminated without the introduction of new or inadvertent faults.

Type PC Cable will fit into your existing system and most certainly can be used for contemplated lines. Our engineers will help you in applying it and will give instructions for installation and maintenance. Write for a copy of our bulletin on Pressure Compensated Cable.

AMERICAN STEEL & WIRE COMPANY

Cleveland, Chicago and New York

Columbia Steel Company, San Francisco, *Pacific Coast Distributors* · United States Steel Export Company, New York

How PRESSURE COMPENSATED CABLE works

In Type PC Pressure Compensated Cable, a gas cushion provided by one or more small tubes included in the impregnated fillers, stabilizes operating pressures within fixed limits. The schematic diagram above shows clearly how it functions.

The helical tubes, perforated at intervals of about four times the length of lay, are filled with dry nitrogen gas. During manufacture, some of the insulating compound is forced into the perforations.

After the cable is installed, slugs of the compound gradually collect in the low portions of the tubes and the gas collects in the domes.

As the cable heats up under load, the compound expands and additional compound is forced into the tubes. The gas trapped between the slugs is compressed and thus acts as a cushion to prevent development of internal pressures which would ordinarily stretch the lead sheath.

In this way, points of concentrated pressure are avoided. Pressure remains uniform and evenly distributed along the entire cable.

When the cable cools, the oil saturant contracts and the compressed gas forces the excess oil back into the cable, thus preventing wide swings from pressure to vacuum.

UNITED STATES STEEL

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ISOLATING TRANSFORMER

DECADE INDUCTANCE

VOLTMETER CALIBRATOR

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N.Y.T. engineers have other postwar projections already in the blueprint stage. Each will fulfill a purpose and need in industry . . . each will formulate a nucleus for continued achievement in the field of electronic engineering. Data on request—no obligation incurred, of course. Write Dept. G

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2. higher dielectric
3. with less varnish build-up
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● These definite improvements in the results obtained with the new Kappa Cellulose Acetate Rayon Tapes, when varnish-impregnated by standard methods, have been proved both by authoritative impartial laboratory tests and by the experience of many leading electrical manufacturers now using Kappa Tapes in regular production.

The KAPPA TECHNICAL BULLETIN gives in detail the results of tests covering both physical and electrical properties of varnished samples, together with specifications and prices. Ask for your copy of this bulletin, also for long length test samples of Kappa Tape in the widths and thicknesses you use. Kappa Tapes are IMMEDIATELY AVAILABLE in standard widths and consistent mil thicknesses . . . including 3, 5, 7, and 10 mil. Write to The Wm. E. Wright & Sons Company, Industrial Textile Division Box 1000, Bridget St., West Warren, Mass.

Complete test and Technical Data and prices in this new Bulletin. Free on request.

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COIL-WINDING TAPES

The Wright tape for every winding..

KAPPA

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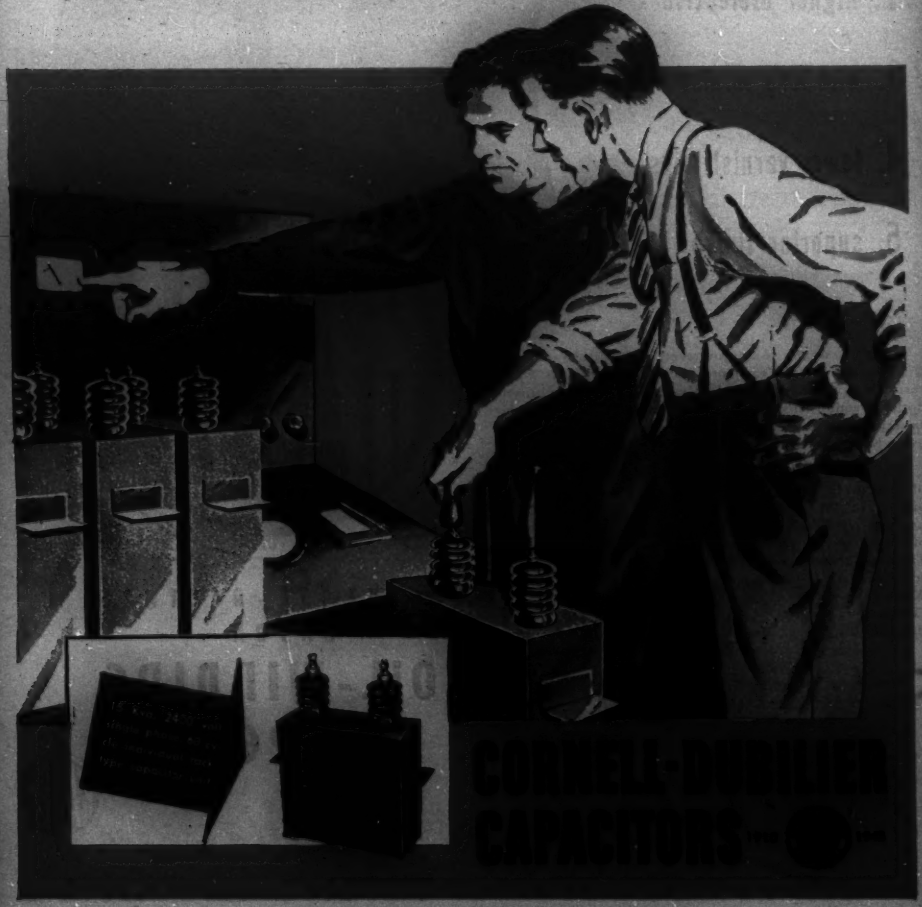
American Industry had to speed up for war production. That meant more electric power—much more. But there was no time to build new generating equipment, nor could we release copper and other critical materials.

CORNELL-DUBILIER ENGINEERS HAD A SOLUTION . . .

C-D Power-Factor Capacitors. They're easy to install quickly, they save man-hours and critical materials.

Like all C-D Capacitors, power factor units *are precision products.* To make sure of their perfection, highly trained men, long skilled in testing capacitors check and recheck repeatedly throughout production.

Devotion to detail is a habit with C-D craftsmen. Their precision methods have made C-D's famed for dependability since 1910. *Look to C-D for capacitors of better-than-specified quality, performance and life.* Cornell-Dubilier Electric Corporation, South Plainfield, N. J. Other Plants: New Bedford, Brookline, Worcester, Mass. and Providence, R. I.



SUCCUSSION RESEARCH..

..ON ELECTRICAL CONNECTORS

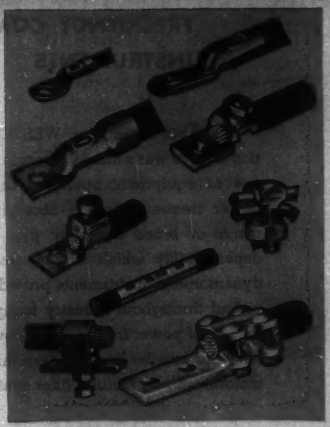
Succussion* in some form . . . from mild vibration to heavy shock . . . is present around every electrical connector in service. If succussion wins, circuit efficiency drops or service stops . . . and costly maintenance begins.

How, then, can you be sure the connections you make, in your product or in your plant, will remain unaffected by mechanical abuse? You'll find the answer here in Burndy's torture chamber where connectors are 'pre-tested' through a rigorous physical 'workout'.

Hour after hour, they are vibrated at varying frequencies and amplitude. But in addition, very unusual methods are employed to add shock, stress and twist as well. After which their electrical resistance and strength are carefully measured to make sure there has been no change . . . that they are worthy of the Burndy name.

These 'physicals' are but part of the thorough test procedure here in the Burndy laboratories . . . all aimed to assure that your circuits or equipment suffer no connection troubles in service. If you don't have the Burndy catalog, let us send you a copy. Burndy Engineering Co., Inc., 107-E Bruckner Boulevard, New York 54, N. Y.

*Succussion: forcible shaking, violent shock.



Headquarters for CONNECTORS

Burndy

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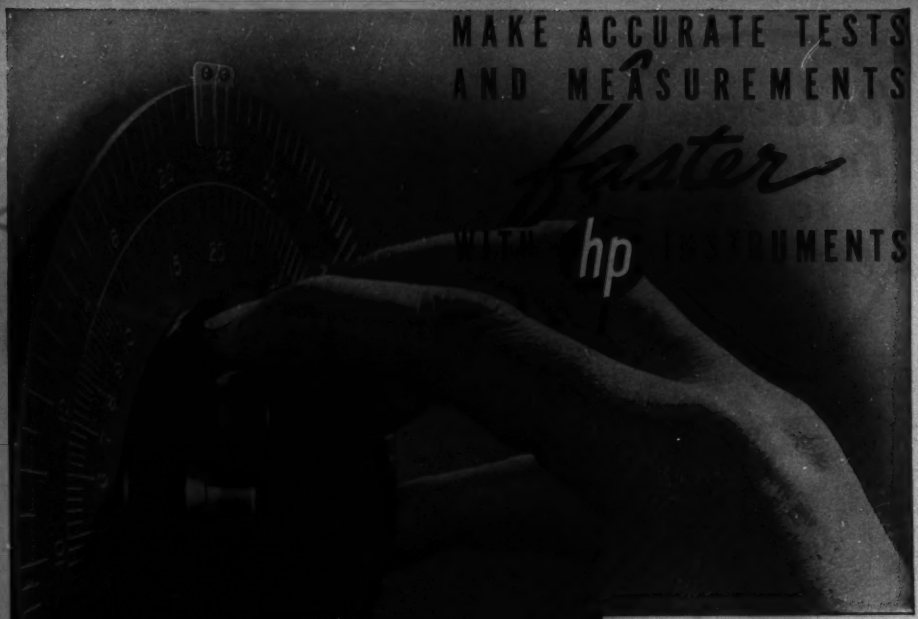

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- *Measure Network Response*
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- *Acoustic Measurement*
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- *Measure Frequency Response*
- *Square Wave Measurement*
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- *Provide Voltage for Bridge Measurement*

Special instruments and combinations of instruments can be supplied to fill your needs. Let our engineers help solve your problem.

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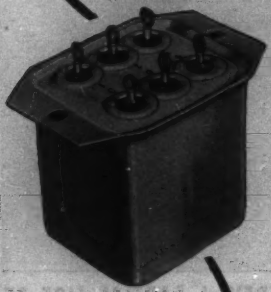
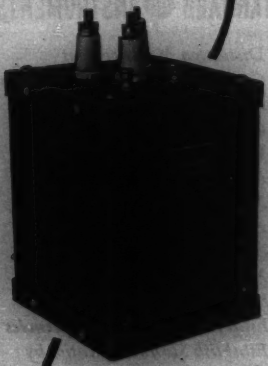


Hermetically sealed, output transformer. Terminals constructed of Pyrex glass with Kovar electrodes and metal collars. Designed and constructed to pass 5 cycle immersion test.



This type T-7029 Filament Transformer with H.V. insulators is one of many designs we have produced. Send your specifications.

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CUBA, NEW YORK • CLYDE, NEW YORK

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LAMINATED PRECIOUS METALS

for New

INDUSTRIAL USES

Gold, silver, platinum and palladium or special precious metal alloys laminated to base metal have made these things possible . . .

- **The desirable electrical, mechanical or chemical qualities of the precious metals have been added to the strength or other desirable properties of base metals, precisely where and as required.**
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- **Finer, more lasting finishes than are otherwise obtainable in base metals.**

Recent production includes gold, silver, or specially developed precious metal alloys on copper, beryllium copper, invar, steel, inconel and pure nickel. Likewise, platinum and palladium are being laminated to inconel and pure nickel. We can manufacture sheet or strip of precious metal laminated to base metal in any combination of metals and in any quality or ratio, single or double plate, striped or edgelay.

To assist you in the application of our products to your products we are maintaining a staff of thoroughly experienced metallurgists, chemists, designers and consultants . . . an up-to-date research and testing laboratory . . . and a splendidly equipped tool room. These are all at your service to cooperate with your own staff to the full extent of our facilities.

Your inquiries are cordially invited. Ask, too, for a copy of our new descriptive folder.

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SIMPLEX-ANHYDREX UNDERGROUND CABLES

NEED NO PROTECTION FROM *Moisture*

Underground cables for electrical distribution are exposed to moisture which can cause a lot of trouble and seriously interfere with service. Metallic sheaths will keep moisture out of the cables but they often create other problems of electrolysis, corrosion, sheath losses and maintenance. A flexible, non-metallic covering, such as a rubber sheath, that will not absorb water is the ideal protection.

Simplex-ANHYDREX Underground cables are now made with synthetic insulations and sheaths that are suitable for underground service in ducts or directly in the ground. Exposure to moisture, even permanent submersion in water, has no effect upon their electrical stability. For steady, uniform underground distribution Simplex-ANHYDREX Underground cables are what you need.

Our experience with low water absorption insulations over many years is at your service whenever moisture creates a cable problem for you.

Buna S has replaced natural rubber in Simplex insulations.

Simplex Wire & Cable Co., 79 Sidney Street, Cambridge 39, Mass.

Simplex

WIRES and CABLES

How

● *The automatic stacking machines shown have enabled Sangamo to play an important part in meeting the heavy and exacting requirements of wartime America. Well-trained operators, adequate facilities, and competent supervision have contributed in some measure in helping the United States to become the world's leader in Electronic developments.*

THESE OPERATORS who assemble Sangamo mica capacitors are fully aware of the dependability required in their performance. They know that full quality must be built into these units to meet the high standard set at Sangamo. Skilled operators, utilizing the most modern mechanical equipment, contribute to the excellence of the finished product, be it the smallest or the largest capacitor.

SANGAMO ELECTRIC

ESTABLISHED 1901 — MICA CAPACITORS

EXCELLENCE IS BUILT INTO....

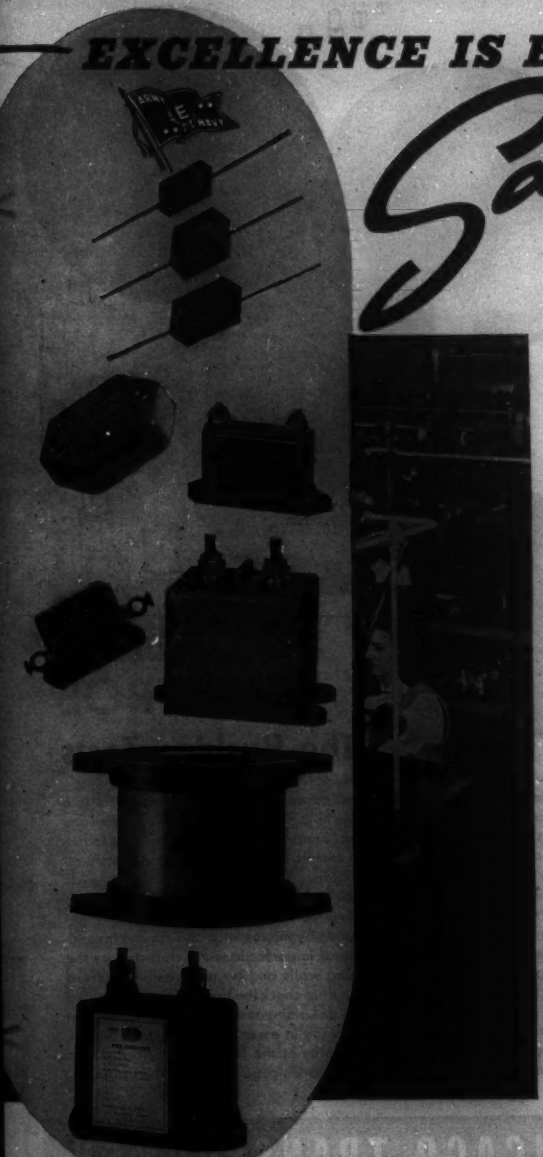
Sangamo

MICA CAPACITORS

•

Capacitor Assembly

•



A MICA CAPACITOR consists of a number of alternate layers of mica film and a conducting metal plate. As the capacity of the unit varies directly with the area of the active surface of the plate and inversely with the thickness of the dielectric, these factors must be accurately controlled in order to produce a satisfactory capacitor.

The assembling or stacking of these units may be done by hand with the use of mechanical stacking fixtures, or automatically, by utilizing special assembly machines. Since 1929, automatic machines, designed and developed by Sangamo, have been used for stacking many types of Sangamo capacitors. This method of stacking has insured accurate positioning of the foil, which is essential for long life and trouble-free operation of any capacitor unit. The automatic assembly machines are designed so that the length of each foil is very accurately controlled; as the mica previously has been gauged to within very close limits and inspected for all defects or flaws, a uniform capacitor results. Since many of the large capacitors consist of series sections and comprise in all many hundreds, and in some cases thousands, of pieces of mica, automatic stacking insures consistent quality and facilitates increased production. A large battery of these assembling machines enables Sangamo to produce many thousands of capacitors of all values each day and each is built with that precision and care required to insure dependable operation in all types of electronic equipment.

COMPANY SPRINGFIELD ILLINOIS

SAVE $5.00 A TURN OR DEADEND

on 000 to 1,500,000 C.M. cable with

Matthews Cable Clamps

Shows how strain caused by right angle taps can be relieved

Outside Turns, Straight Guys

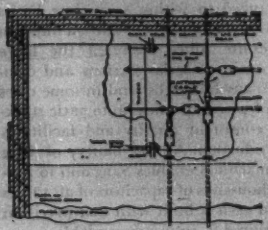
Deadending Two Cables

Order Number 2 for use on D.C. Cable or Number 3 for use on A.C. Cable.

Hundreds of thousands of these Clamps have been sold.

Every order for 000 to 1,500,000 C.M. Cable should include an order for Matthews Cable Clamps for every corner or deadend.

Write for Bulletin C.



Right Hand Turns in Heavy Cable

W. N. MATTHEWS CORPORATION

ST. LOUIS, U. S. A.

QUALITY CONTROL

The Bushing Tests

The maintenance of uniformity and accuracy in component parts is a recognized prerequisite of quality in a finished transformer, as in any precision product. For this reason, important parts of Chicago Transformers are closely inspected and tested for structural and dimensional accuracy before they reach production.

Ceramic bushings, a vital part of Hermetically-Sealed Chicago Transformers, are subjected to exhaustive tests and inspections. Dimensional accuracy to close tolerances is insured by micrometer and gauge inspection, while internal flaws and structural imperfections are detected by the use of light directed through bushing walls and by air-pressure exerted upon each bushing under water. As a final check the bushings are subjected to a high-voltage breakdown test to determine their insulating properties.

By this type of close control of quality in essential parts, production is facilitated and high standards of quality in the finished transformer are maintained. The result—better service to Chicago Transformer customers.

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DIVISION OF ESSEX WIRE CORPORATION

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The Standard of Quality for a Third of a Century

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HICKOK Instruments have long been known as the ultimate in scientific development. Illustrated here are but 4 of our 36 leaders in the Radio Service field. Thousands of Radio Service men have preferred HICKOK Instruments because of their unusual accuracy and dependability. • HICKOK pioneered in Dynamic Mutual Conductance Tube Testing Equipment. In the field of Signal Generators, Traceometers, Vacuum tube Voltmeters, Oscillographs, Zero Current Testers, Volt-ohm-milliam-meters and Industrial Analyzers the name HICKOK is assurance of excellence.

THE HICKOK ELECTRICAL INSTRUMENT COMPANY

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(Ground Tester)

Good, permanent man made ground connections are necessary to protect men and electrical equipment. Eliminate the danger of lightning damage or static discharges by frequent testing of ground connections with VIBROGROUND. Do it accurately and quickly with VIBROGROUND.

Model 251 VIBROGROUND (illustrated) has triple range, 0–12.5, 0–125, 0–1250 ohms. Is complete with batteries, ready to operate. Recommended for use where average ground conditions prevail. (Model 255 has four ranges, for extremes of dryness or moisture.)

Engineered to Assure Greatest Accuracy

Open scales for direct reading. No calculations necessary. No reverse readings nor polarization errors. Excludes "strays" from high potential networks, DC ground currents, AC commercial frequencies. Here are controlled sensitivity, dependability and *accuracy* at all times.

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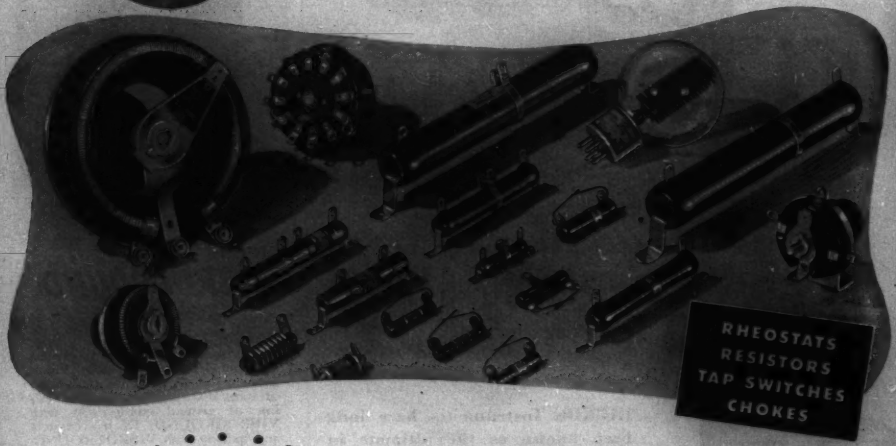

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VIBRATION
TEMPERATURE EXTREMES
HUMIDITY
ALTITUDE

● Because they are so consistently reliable in actual service . . . Ohmite Rheostats, Resistors, Chokes and Tap Switches have become *"the control engineer's control units."*

Shown here are a few of the many types extensively used in military and industrial equipment. The wide variety of types and sizes in stock or special units provides a ready and exact answer to most applications.

In designing for war or postwar, let Ohmite experience help you.

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MULTIPRESS

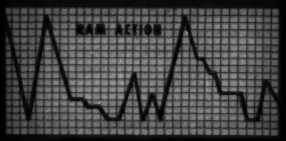
the four-ton giant in midget form

If your war production requires up to 4-ton pressing operations . . . for staking, crimping, punching, bending, assembling, or whatever . . . MULTIPRESS can speed it! There are mechanically and automatically controlled MULTIPRESSES. In the mechanically controlled type, illustrated here, there are three different ram actions to choose from . . . and if pressing enters into your production, one of these three actions will very likely fit it and speed it!

Basic Unit
$575.00

Patents Applied for

1



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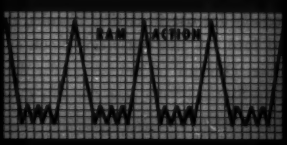


In all models, single hand-lever or foot-pedal control may be substituted for the dual hand-levers, and ram travel may be adjusted anywhere between 1/16-inch and 6 inches. Maximum daylight opening between ram and table is 11 inches. Maximum stroke 6 inches. Matching benches, table extensions, side shelves, and a variety of bolster plates are available. Write for details of MULTIPRESS, the production giant with amazing ram action control!

The DENISON Engineering Co., 1192 Dublin Rd., Columbus 16, Ohio

DENISON
EQUIPMENT for APPLIED
Hydraulics

SEND TODAY *for this complete bulletin on the new* MULTIPRESS

TELEVISION, SINCE PIONEER DAYS, HAS DEPENDED UPON CANNON PLUGS

Because Cannon Plugs and Receptacles were designed especially for use in critical circuits, they were incorporated into the first television hook-ups. Says Harry R. Lubcke, Director of Television for the Don Lee Broadcasting System: *"We find Cannon Connectors indispensable in our television operations. We called on Cannon in 1937 and what was probably the first all-television connector was fabricated."*

All the circuits of a modern television camera pass through this single master Cannon Connector mounted on the side of the instrument. Equipment for the control of focusing, power and intensity of image is connected to power sources and to pick-up and broadcasting equipment through Cannon Plugs.

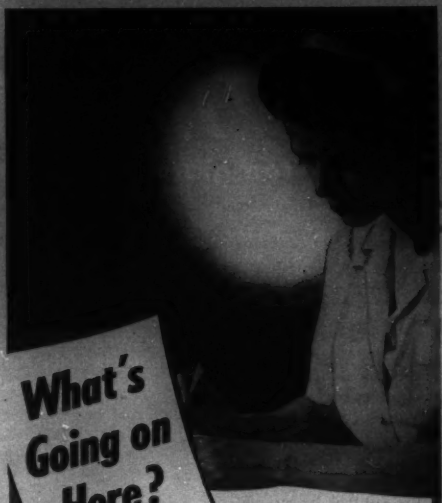
If you are interested in equipment of this kind, write for the Cannon Condensed Catalog. Address Dept. A-511, Cannon Electric Development Co., 5209 Humboldt St., Los Angeles 31, Calif.

CANNON ELECTRIC

Cannon Electric Development Co., Los Angeles 31, Calif.

Canadian Factory and Engineering Office: Cannon Electric Co., Ltd., Toronto, Canada

Representatives in Principal Cities — Consult Your Local Telephone Book

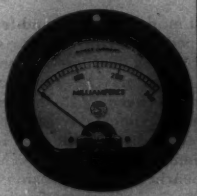


What's Going on Here?

The *what* we can tell you about. The *how* is one of those many little secrets about instrument manufacture Simpson has learned through more than 35 years of experience. This particular operation has to do with the making of pivots, those critical parts around which the accuracy of any electrical instrument revolves. Only by means of this and other Simpson-developed processes can we make pivots which in strength and hardness, and in their perfect contour, measure up to Simpson's standard.

The Simpson plant is full of such refinements and shortcuts—all aimed at the twin purpose of improving performance and reducing cost. Added to the basic superiority of the patented Simpson movement they provide the fullest measure of accuracy and stamina, and dollar value.

Only Simpson's long familiarity with the problems of instrument manufacture could achieve so many noteworthy solutions. Nothing less can promise so much for the electrical instruments and testing equipment you will use in the years to come.

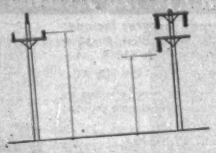


SIMPSON ELECTRIC CO
5200-18 W. Kinzie St., Chicago 44, Ill.

Simpson

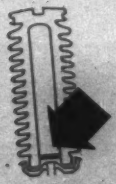
INSTRUMENTS THAT STAY ACCURATE

LINE POST CONSTRUCTION IS ECONOMICAL FOR CONVERSION TO HIGHER VOLTAGES *OR* NEW BUILDING

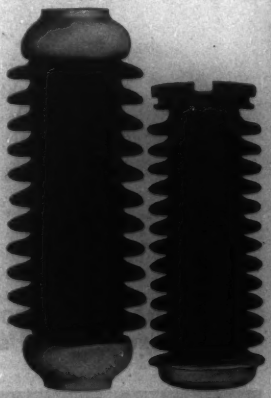


Any still-sound transmission line can be converted to higher voltage at low expense—and economically of manpower—by reinsulation on Line Posts. Ordinarily only new cross-arms and insulators are needed, and the job can be done with hot-line tools or during low-demand hours. For new construction, Line Posts offer substantial advantages in cost and operating performances. Because of the Line Post's upright height, it provides extra ground clearance —or in some cases the opportunity to use poles of the next shorter length.

LAPP LINE POSTS ARE LONG-LIVED... ALL HARDWARE EXTERNALLY ATTACHED



A feature of the Line Post in the original Lapp design was the *external attachment of all hardware*, and the elimination of nested porcelain parts. An inherent characteristic of porcelain is that it is at least ten times as strong in compression as in tension. Much of the failure from cracking in conventional insulators comes from bursting tension forces induced by thermal change. Lapp considers that its original conception was sound, and offers Line Post and Station Post insulators with all hardware externally attached—and still claims "*no cracking*" as a feature of these units.



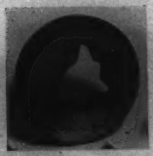
Lapp

LAPP INSULATOR COMPANY, INC., LE ROY, N. Y.

WITH red points as scarce as they are, this mistake is understandable but, when a design engineer says he wants a field of 3500 *GAUSS*, the chances are good that he has something else in mind—possibly a permanent magnet.

And if it *is* a permanent magnet, it's an odds-on bet that he'll be tough about such details as size, shape, weight, allowances for grinding and other factors he considers essential.

Neatest way out of any such situation is to humor him—"Yes" him—tell him to stay right where he is while you get in touch with Cinaudagraph, where they speak his language.



Typical of the many varieties of Permanent Magnets designed and made by CINAUDAGRAPH.

CINAUDAGRAPH CORPORATION

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CINAUDAGRAPH CORPORATION

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DELAY RELAYS

PROVIDE DELAYS RANGING FROM 1 TO 120 SECONDS

Other important features include:

1. Compensated for ambient temperature changes from —40° to 110°F.
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3. Hermetically sealed — not affected by altitude, moisture or other climate changes . . . Explosion-proof.
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5. Compact, light, rugged, inexpensive.
6. Circuits available: SPST Normally Open; SPST Normally Closed.

WHAT'S YOUR PROBLEM? Send for "Special Problem Sheet" and Descriptive Bulletin.

with porcelain heater

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If you can offer this:

Sound electrical or mechanical engineering experience (with the equivalent of a university degree) . . . ability to qualify as a project engineer, at once or with a few years' more training . . . above-average intelligence and will to get ahead . . . and perhaps some design experience connected with governors or small electric switches,

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An excellent opportunity in keeping with your training and experience in a firmly established, growing company with plants in five Eastern cities, all of which are 100% engaged in war work. Our products are varied, and have established peacetime markets. Openings range up to the level of Chief Engineer for one of our new plants.

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Write me personally, telling your experience, background, and qualifications in detail, and salary expected. Don't hesitate if you happen to be over forty. Your letter will be treated with complete confidence, and no further investigation will be made without your express permission.

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Walter F. Skillin, Vice President in Charge of Engineering

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RADIO, SOUND and COMMUNICATIONS EQUIPMENT

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WANTED
Copies of the **August, September and November (1944)** issues of ELECTRICAL ENGINEERING. Please mail (parcel post) to American Institute of Electrical Engineers, 33 W. 39th St., New York City, printing your name and address upon the enclosing wrapper. Twenty-five cents plus postage, will be paid for each copy returned.

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In applying for positions advertised by the Service, the applicant agrees, if actually placed in a position through the Service as a result of these advertisements, to pay a placement fee in accordance with the rates as listed by the Service. These rates have been established in order to maintain an efficient, non-profit personnel service and are available upon request. This also applies to registrants whose notices are placed in these columns.

All replies should be addressed to the key numbers indicated and mailed to the New York Office.

Men Available

HYDRO-ELEC ENGR, 45; varied exper, power plants, sub-stations, transm, overhead and underground distr, load dispatching, repairs and winding of motors and transformers, etc. Mixing exper. Good knowledge all elec calculations. Desires pos Latin America. E-97.

ELEC ENGR, 45; graduate, family. Twenty-three yrs exper in pub util, designing, engg, and supervising elec constr. Desires pos as fire protection, sales or application engr. E-98.

Positions Available

ENGINEERS. (a) Engineer for research and development of devices involving electronics, followups and remote control systems. Analytical and mathematical ability important. Salary, $5000–$7000 a year. (b) Design Engineer, electrical graduate, experienced in design of telephone equipment. Salary, $6000 a year. Location, New York, N. Y. W-5108.

ENGINEERS. (a) Project Engineers, 2. One with experience on high speed switches and the other experienced on governors. Salary, $6000–$10,000 a year. (b) Development Engineer, preferably with experience on communications and other electro-mechanical circuits. Salary, $6000–$10,000 a year. (c) Inspection Process or Inspection Methodizing Engineer to establish inspection standards, methods and procedures. Will act as assistant to the Superintendent of Inspection. Salary, $4420–$5980 a year. (d) Time Study-Methods Engineer, preferably with experience on small electrical parts. Salary, $3900 a year; Location, Connecticut. W-5149.

ELECTRICAL ENGINEER, graduate or equivalent, with minimum of two years' experience in electrical switch gear engineering and four years in the operation and maintenance of electrical power plant equipment for work along these lines. Salary, $5238 a year, on a 48-hour week basis. Location, Florida. W-5172(d).

DESIGNER, electrical or mechanical graduate, 30–40, to take complete charge of an engineering department. Must be thoroughly experienced in shop practice, including the design of tools, jigs and fixtures and have a working knowledge of all materials including plastics. Must be capable of low cost production design of relays, meters, circuit breakers, switches, etc. Executive and administrative ability is essential. Apply stating education, experience, references and salary desired. Location, New Jersey. W-5173.

SALES PROMOTION ENGINEER, 35–40, electrical graduate, with distribution transmission line experience. Must be Canadian citizen. Salary, $5000 a year. Headquarters, Toronto or Montreal. W-5175.

FIELD ENGINEER, 30–45, electrical or mechanical, with some sales experience, to contact all types of industrial plants to sell and design V-belt power transmission equipment consisting of the V-belts and sheaves as well as molded rubber goods and all types of industrial hose. Salary plus bonus and expenses. Must have a car. Headquarters, Ohio. W-5178D.

ENGINEER, electrical, civil or mechanical, experienced. Must be skilled engineer with welding experience, administrative ability and thoroughly familiar with rotating machinery. Work will consist of supervising the engineering and final construction of a large aeronautical, high speed variable density wind tunnel. Duration, nine to fifteen months. Salary, $10,000 a year. Location, upstate New York. W-5192.

ELECTRICAL ENGINEER to assume full charge of operation and maintenance and to plan and oversee designs for expansion of a publicly owned power system with annual sales of 100,000,000 KWH. Must have administrative as well as technical ability. Permanent, good opportunity. Location, California. W-5204.

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...Ready to Meet Your Requirements!

Up to 10 MFD. Capacity

Sturdy Single Hole Mounting

No Brackets Needed

Catalog Number	Capacity in MFD.	Working Voltage D.C.	DIMENSIONS IN INCHES A	B	C	D	E	F
6EC300	2.0	600	2¾	1½	¼x10bd	1	1½	½
6EC300	3.0	600	4½	1½	¼x10bd	1	1¾	½
6EC400	4.0	600	4½	1½	¼x10bd	1	1¾	⅝
6EC600	6.0	600	4	2	1x14bd	1⅛	1⅝	1
6EC800	8.0	600	4½	2	1x14bd	1⅛	1⅝	1
6EC1000	10.0	600	6	2½	1x14bd	1⅛	2⅛	1
10EC100	1.0	1000	2¾	1½	¼x10bd	1	1¾	½
10EC200	2.0	1000	4½	1½	¼x10bd	1	1¾	½
10EC400	4.0	1000	4	2	1x14bd	1⅛	1⅝	1
10EC600	6.0	1000	4	2½	1x14bd	1⅛	1⅝	1
10EC800	8.0	1000	4½	2½	1x14bd	1⅛	1⅝	1
15EC50	.5	1500	2¾	1½	¼x10bd	1	1¾	½
15EC100	1.0	1500	4½	1½	¼x10bd	1	1¾	½
15EC200	2.0	1500	4	2	1x14bd	1⅛	1⅝	1
15EC400	4.0	1500	4½	2½	1x14bd	1⅛	1⅝	1

All of the Above A.W.S. Army-Navy Submersion Proof Units Available in Production Quantities for Prompt Delivery. Write, Wire or Telephone—Now.

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DONJON-

Centuries ago, when potential besiegers lurked in every forest glade, castles were prepared to withstand violent assault in the event that the outer works were penetrated. A secondary "point d'appui" or strong point, had to be in readiness. Thus each fortress had a Donjon—a huge square tower defying current methods of attack. Secure as Donjons were from without, they were weak from within; the summer heat was torrid, the winter cold severe, and sanitary and living conditions were unbearable. Surrender oftentimes was the wiser choice.

In Industry, products must have the inherent ability to meet diversified operational requirements. MORGANITE Carbon Brushes, embodying specialized experience of many years, offer this wide-scope application suitability. Inquiries are invited: write to Morganite Brush Co., Inc., Long Island City 1, N.Y.

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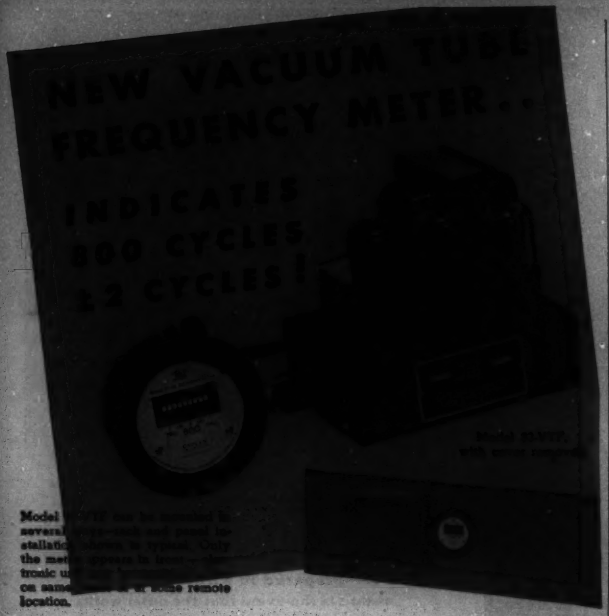

Model 33-VTF can be mounted for several [illegible] panel for installation [illegible] as shown. Only the meter appears in front of panel. Electronic unit can be mounted at some remote location.

MODEL 33-VTF, now released for commercial use, makes available the ruggedness and exceptional accuracy of the vibrating reed frequency meter. It measures specific bands such as 760-840 cps or 1140-1260 cps.

Again, J-B-T engineers have extended the useful range of the vibrating reed frequency meter—through use of a simple, practical electronic circuit. A vacuum tube multivibrator divides the incoming frequency by the proper integer, and shows the result on the widely used standard 400 cycle meter.

Harmonics of accidental frequencies or unusual wave form do not affect the response where the speed of the inverter or other frequency source is in the approximate range being measured.

Model 39-VTF, Laboratory Type, not shown, has an input impedance of 500,000 ohms, and uses regular line current for power supply. This model, through use of a multiplier switch, measures frequencies 1, 2, 3, 4, 6 and 9 times the basic range of 380-420 cycles.

Check These Features:

EXTREME ACCURACY . . . within 0.25% of frequency measured.

PERMANENT ACCURACY . . . calibrated at factory — no subsequent calibration or standardization required at any time.

STABILITY . . . no temperature drift after initial 30 second warm-up period. Accuracy is independent of line voltage variation. No voltage regulator, external or internal, is required.

BURN-OUT PROOF . . . no protection needed against accidental frequencies above the range being measured.

SIMPLE — LIGHTWEIGHT — COMPACT . . . only 3 tubes—6N7 multivibrator, 6V6 amplifier, 6X5 rectifier. Weighs only 6 lbs. . . . electronic unit 5½" x 6" x 4¼"; meter meets JAN-I-6 mounting dimensions for 3½" instruments.

20 WATT POWER CONSUMPTION . . . derived from frequency source being measured.

J-B-T

(Manufactured under Triplett Patents and/or Patents Pending)

4-JBT-2

Another

Du MONT *Contribution*

★ Out of the rigorous trials of military service there emerges a still better Type 208 DuMont Oscillograph.

Increased voltage ratings for certain capacitors; use of mineral-oil-impregnated hermetically-sealed paper capacitors; additional mounting straps, tube clamps, elastic stop nuts and other mechanical reinforcement; certain tube changes; inclusion of frequency range adjustment for accurate time-base frequency setting—in every instance the change or refinement aims at improved electrical or mechanical performance.

Thus an already popular oscillograph which has found the widest usage in peace times becomes a better, more rugged and more dependable instrument under the trying conditions of field service

★ **Write for literature.**

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COMPACT!

IRC's NEW FINGERTIP CONTROL ANSWERS SPACE-SAVING PROBLEMS

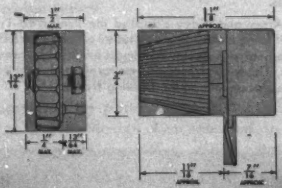
No bigger 'round than a nickel and wafer thin, this new Fingertip Control will find many important applications in miniature electronic devices. An all-inclusive unit, its unique design eliminates the usual bulky knob, shaft and bushing without any impairment of functional operation.

Of neat appearance and available in either black or colors, this Type H control is intended for edgewise installation. A light-pressure, fingertip rotation of the knurled edge of the cover permits ready resistance adjustment.

Embodying suitable mechanical strength and many of IRC's famous features as found in Type CS and D controls, the Fingertip Control has a rotation of 290°, a power rating of 0.25 watts and 500 ohms to 3 megohms, as standard resistance values. Fingertip Control may be had with linear taper or with standard audio tapers.

Inquiries are invited from interested manufacturers of hearing aids and other miniature equipment. Engineering Bulletin on the Type H control is now in preparation.

OCCUPIES LESS THAN HALF CUBIC SPACE REQUIRED FOR CONVENTIONAL TYPES



IRC

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How to Lower Your Tube Costs

Simply base your designs on RCA Preferred-Type Tubes which, in a single year, dropped more than 13% in price

Not only have prices been lowered by the Preferred-Type Program but the quality of the tubes has been improved, due to longer production runs and increased skill of workers.

How the preferred-type idea started

Long before Pearl Harbor, RCA found that despite the hundreds of different receiving-tube types being manufactured, almost every possible circuit requirement could be satisfied by a list of less than 50 tube types.

Moreover, by limiting the number of types being manufactured, it would be possible to realize tremendous savings in warehousing, distribution, test equipment, and other factors affecting cost.

The plan was promoted among equipment designers who, quick to see the advantages of fewer tube types, cooperated wholeheartedly to make the Preferred-Type Program a success.

When the war broke out, the Army and Navy adopted the Preferred-Type Idea and established a list of their own, including many tubes already on RCA's Preferred-Type list. Military equipment was designed almost exclusively around Army-Navy Preferred-Type Tubes. This forward-looking policy simplified military tube stocks and insured speedy replacements on the fighting fronts.

Which RCA tubes are preferred types

By substantial indication of preference, designers themselves — not RCA — determine which tubes are Preferred Types.

Because the list of Preferred Types (metal, miniature and glass) is still rather fluid, it is advisable to check with us before your final decisions are made regarding any specific tube. Write to Department 82-28A, RCA, Harrison, N. J.

The foremost name in modern Tube development is RCA.

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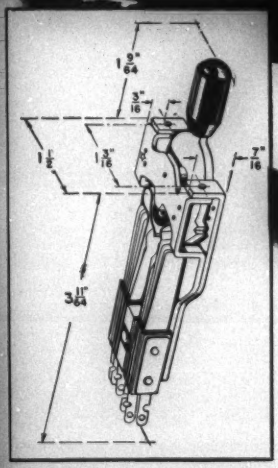
FEDERAL'S *New* LEVER KEY



- Small Size—5/8" horizontal mounting centers.
- Large Spring Capacity — 18 springs; over 500 possible combinations.
- Palladium Contacts . . . Nickel Silver Springs.
- High-Quality Phenolfibre Insulation.
- Universal Cam — 1 or 2 way — locking or non-locking.
- Free-Moving Roller . . . Positive Snappy Action.

Designed for finger-tip control of electronic and communications equipment where size is important, the FTR-810 Series Lever Key occupies less than half the horizontal mounting space required for older types.

And at the same time, its eighteen nickel-silver springs and low-resistance palladium cross-bar contacts permit more than five hundred possible switching combinations.

High-quality phenolfibre insulated throughout, the overall simplification in design has resulted in a more rugged, dependable lever key with a positive, snappy action that once set — stays set.

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